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AN EVALUATION OF LAND USE, HYDROLOGY, AND SEDIMENT YIELD IN THE MILL CREEK WATERSHED, NORTHERN CALIFORNIA

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TECHNICAL REPORT 17

AUGUST 1986

SEDIMENT BUDGET PROJECT

In 1978, the National Park Service initiated a study project to investigate and quantify sediment source areas, sediment storage, and sediment transport processes which may affect park lands. Results are presented in a series of Technical Reports and Data Releases, and condensed versions will be published in scientific journals.

Measurements in this study are reported in metric units, unless the original source of the data reported measurements in English units. Where metric units are used, English equivalents are given in parentheses.

NOTICE

This document contains information of a preliminary nature, and was prepared primarily on an interim basis. This information may be revised or updated before publication in scientific journals.

AN EVALUATION OF LAND USE, HYDROLOGY, AND SEDIMENT YIELD IN THE MILL CREEK WATERSHED, NORTHERN CALIFORNIA

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ABSTRACT

The Mill Creek watershed (100 km^2) in northwestern California has undergone timber harvest since the 1850's. Two-thirds of the basin is privately owned and, as of 1984, 60% of that portion has been logged. The remaining third of the basin is under state and federal park management.

Most of the Mill Creek basin is underlain by competent sandstone of the Franciscan Assemblage. Sediment yields from the basin are lower than from nearby basins that are composed of more erodible bedrock. Total load in Mill Creek is about 140 t/km^2, of which 60% is suspended sediment, 10% bedload, and 30% dissolved load.

In Mill Creek, a tributary of the Smith River, mean annual runoff is 180 cm and mean annual precipitation is 266 cm. The 1.5, 10, 50 and 100-year recurrence interval floods at the Mill Creek gaging station ($A=74.1$ km^2) are 70, 115, 140 and 150 m^3/s respectively. Mill Creek runoff closely mimics that of the Smith River, and the latter can be used as a surrogate for Mill Creek when the Mill Creek gage is not in use.

Cross section surveys from 1974-1985 show recent scour following deposition in the 1970's. Over a meter of aggradation occurred at the mouth of Mill Creek since 1930. The channel changed most dramatically during high flow years. Bank erosion was common, but not severe, along the upper reaches of Mill Creek. Small slope failures are also common, but large-scale earthflows and debris slides typical of nearby basins are rare in Mill Creek.

The total volume of sediment (active channel sediment plus stable sediment) stored in Mill Creek on a per unit basis is 74,000 m^3/km^2. This is over three times the amount of sediment stored in Redwood Creek. However, active channel sediment represents only one percent of the total stored sediment in Mill Creek. Abundant low-lying terraces along Mill Creek help protect the base of hillslopes from erosion, resulting in fewer streamside landslides than in adjacent basins.

Old growth redwood groves located in park lands are situated on terraces well above the area affected by recent aggradation and are not currently threatened by channel changes in Mill Creek.

ACKNOWLEDGEMENTS

We wish to express our gratitude to Miller-Rellim Timber Co. for allowing us access to cross sections, and to the Del Norte County Timber Assessor's office for the use of aerial photographs. Review comments by Danny Hagans, John Sacklin, Lee Purkerson and Sandi Potter are much appreciated. Sandi Potter assisted in drafting the figures for this report. Vicki Ozaki and Dave Best provided both computer assistance and valuable input in the field. Patricia Hardt helped prepare the erosional features map. And, finally, we thank the clerical staff of the Arcata Office, Redwood National Park.

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I. INTRODUCTION

Redwood National Park, through Public Law 95-250, was directed in 1978 to initiate erosion studies, including slope rehabilitation and stream monitoring programs, in drainage basins encompassing park lands. Because 33.8 km^2 of Mill Creek's lower basin is located within Redwood National Park, this watershed has been included in these studies. Timber operations in the Mill Creek basin upstream of the park boundary may cause an impact on downstream riparian and aquatic park resources. The purpose of the present study was to acquire benchmark information to describe and predict possible stream changes and to make management recommendations.

The park's involvement in Mill Creek began in 1973 when the National Park Service, in cooperation with the U.S. Geological Survey (USGS), initiated studies to measure and evaluate selected characteristics of the basin. These included annual surveys at established cross sections along the lower Mill Creek channel, measurements of erosional processes, and streamflow measurements (Iwatsubo and others, 1976). Streamflow measurements were discontinued in 1981; nevertheless, Redwood National Park has continued the annual channel surveys since 1982.

This report summarizes studies conducted in the Mill Creek watershed by the National Park Service and USGS. The scope of the report is limited to the presentation of (1) physical data, including streamflow characteristics, flood frequency analysis, sediment discharge and size distribution, cross-section surveys, sediment storage features, and distribution of erosional landforms; (2) descriptive data from aerial photographic interpretation, current geological studies and soil-vegetation indices; (3) a brief comparison with physical processes active elsewhere in the park; and (4) management recommendations for future action in the watershed.

II. DESCRIPTION OF STUDY AREA

The 99.7 km^2 Mill Creek drainage basin (a major tributary of the Smith River) is located approximately 4 km east of Crescent City (Figure 1). Nearly 70%, or 60.7 km^2, of the basin is held in private ownership. Redwood National Park and the U.S. Forest Service manage the remaining 39 km^2, which are located primarily in the western and northern sections of the basin.

A. Climate

The climate of the Mill Creek basin is coastal Mediterranean characterized by high winter precipitation (70 to 115 in., or 178 to 290 cm per year) (Figure 2). Proximity to the ocean results in mild temperatures and short, dry summers with frequent fog (Bradford and Iwatsubo, 1978). Precipitation varies widely from year to year. It is greatest at high elevations and on windward (southwest) slopes, but tends to decrease overall near the coast (Winston and Goodridge, 1980).

Most precipitation occurs as rain from large storm systems generated over the Pacific Ocean. Snow falls sporadically at higher elevations but accumulations do not exceed 0.6 m. Near the coast, some precipitation also occurs as fog drip (Bradford and Iwatsubo, 1978). Figure 3 is an isohyetal map depicting precipitation distribution in the Mill Creek basin. Based on this map, Winston and Goodridge (1980) computed mean annual precipitation for Mill Creek to be 101.73 in. (258 cm). Rainfall intensities for the Smith River region, which includes Mill Creek, are listed in Table 1.

Table 1: Rainfall Intensities for Northern Mountains*

	Return Period	
	2-yr	100-yr
1 hr	0.70 in. (1.78 cm)	1.8 in. (4.57 cm)
2 hr	3.5 in. (8.89 cm)	7.35 in. (18.67 cm)
24 hr	6.5 in. (16.51 cm)	14.3 in. (36.32 cm)

*from Elford and McDonough (1964)

Air temperatures measured at Crescent City near Mill Creek vary from 41-67°F (4-19.5°C), but may be more extreme within the Mill Creek basin. Potential evapotranspiration in Mill Creek is estimated to be 25-30 in/yr (63.5 - 76.2 cm/yr) whereas actual evapotranspiration may be only 10-20 in. (25 to 50 cm) (Elford and McDonough, 1964).

B. Vegetation

The Mill Creek basin is blanketed by a dense forest of old- and second-growth mixed redwood and Douglas fir. Redwood-dominated stands occupy the floodplain, low terraces and adjacent slopes in the north

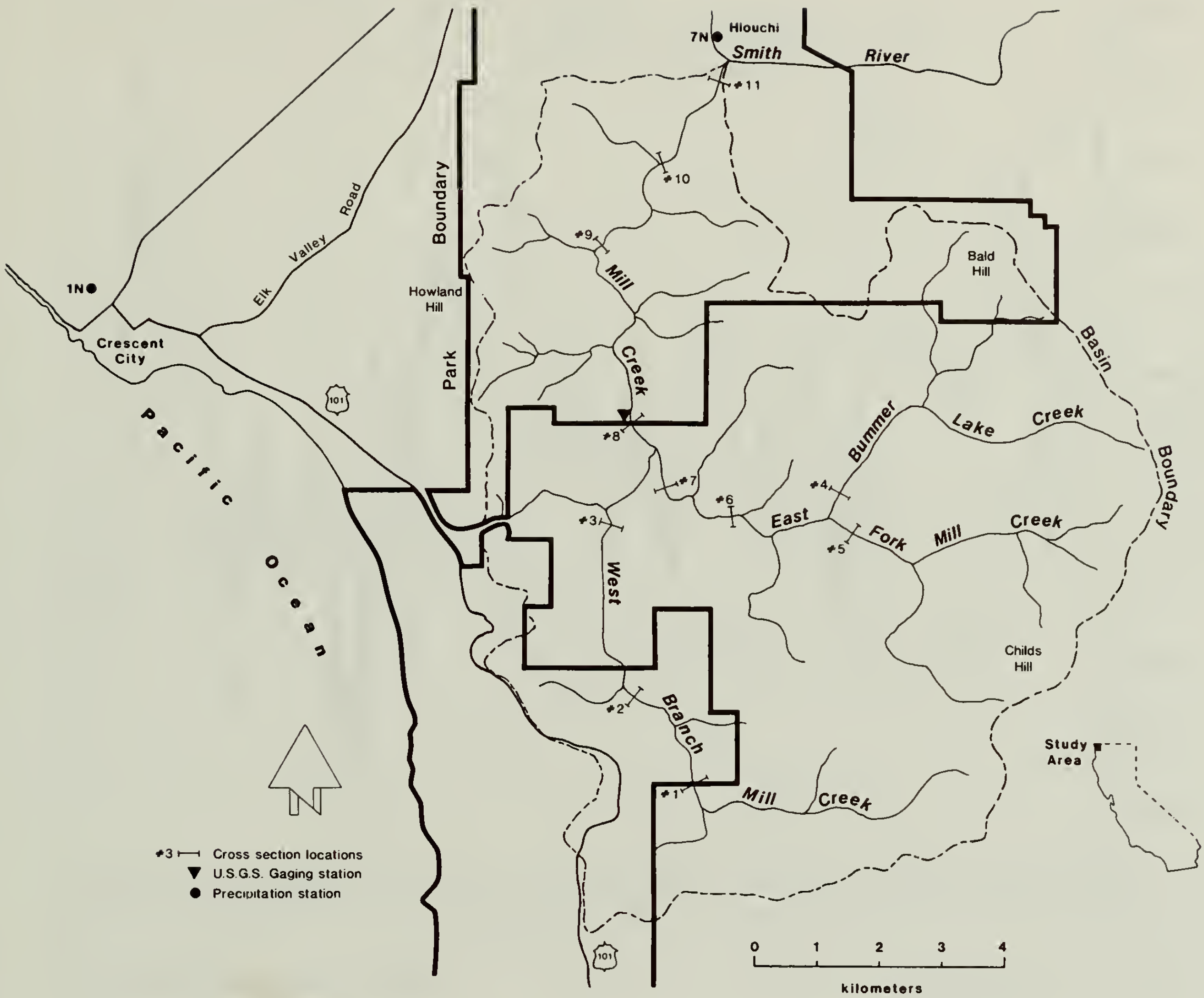


Figure 1: Map of the Mill Creek watershed showing locations of cross sections, the U.S.G.S. gaging station, precipitation stations, and park boundaries.

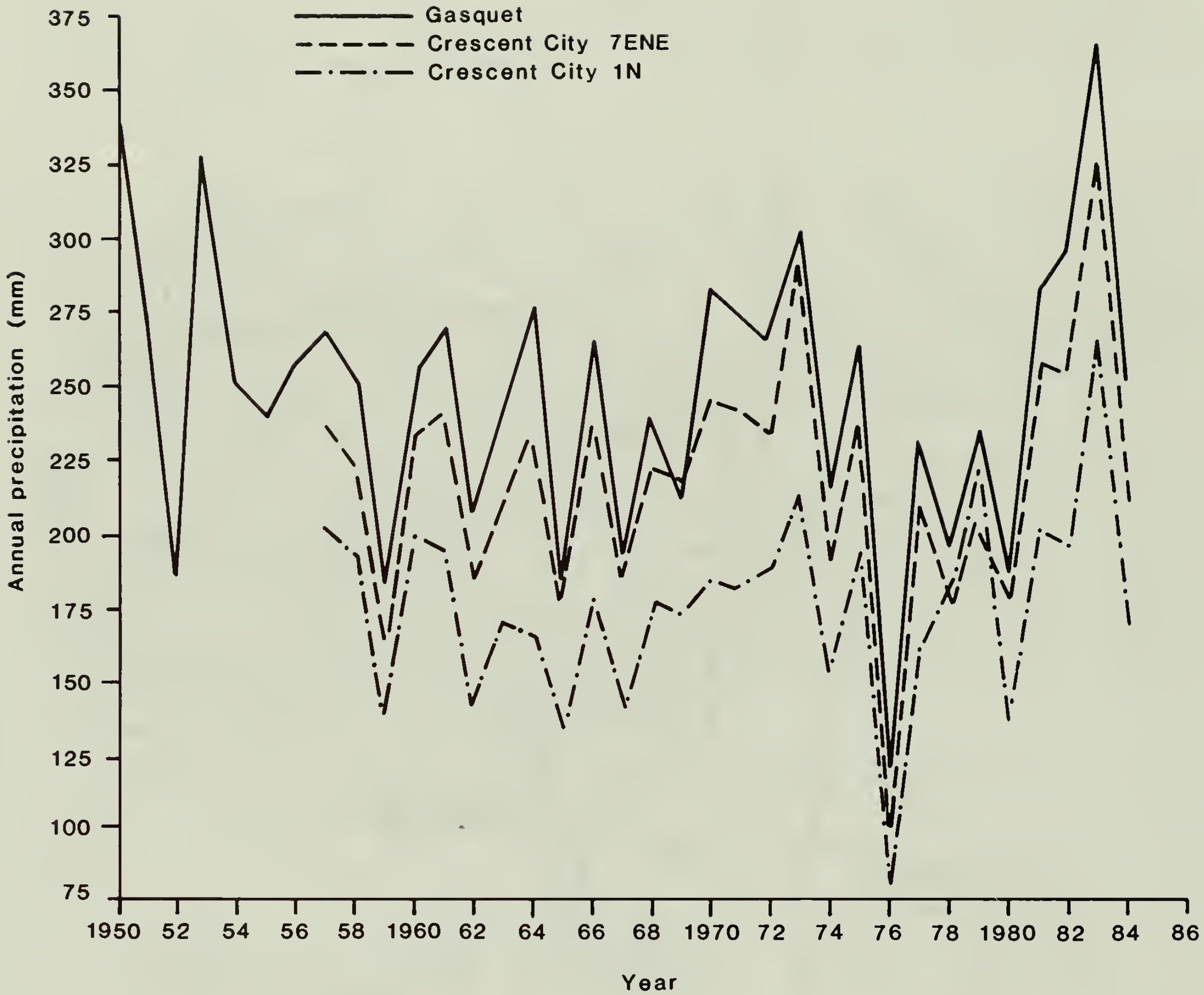


Figure 2. Plot of annual precipitation for three stations near Mill Creek, which were used to compute mean annual precipitation for the Mill Creek basin.

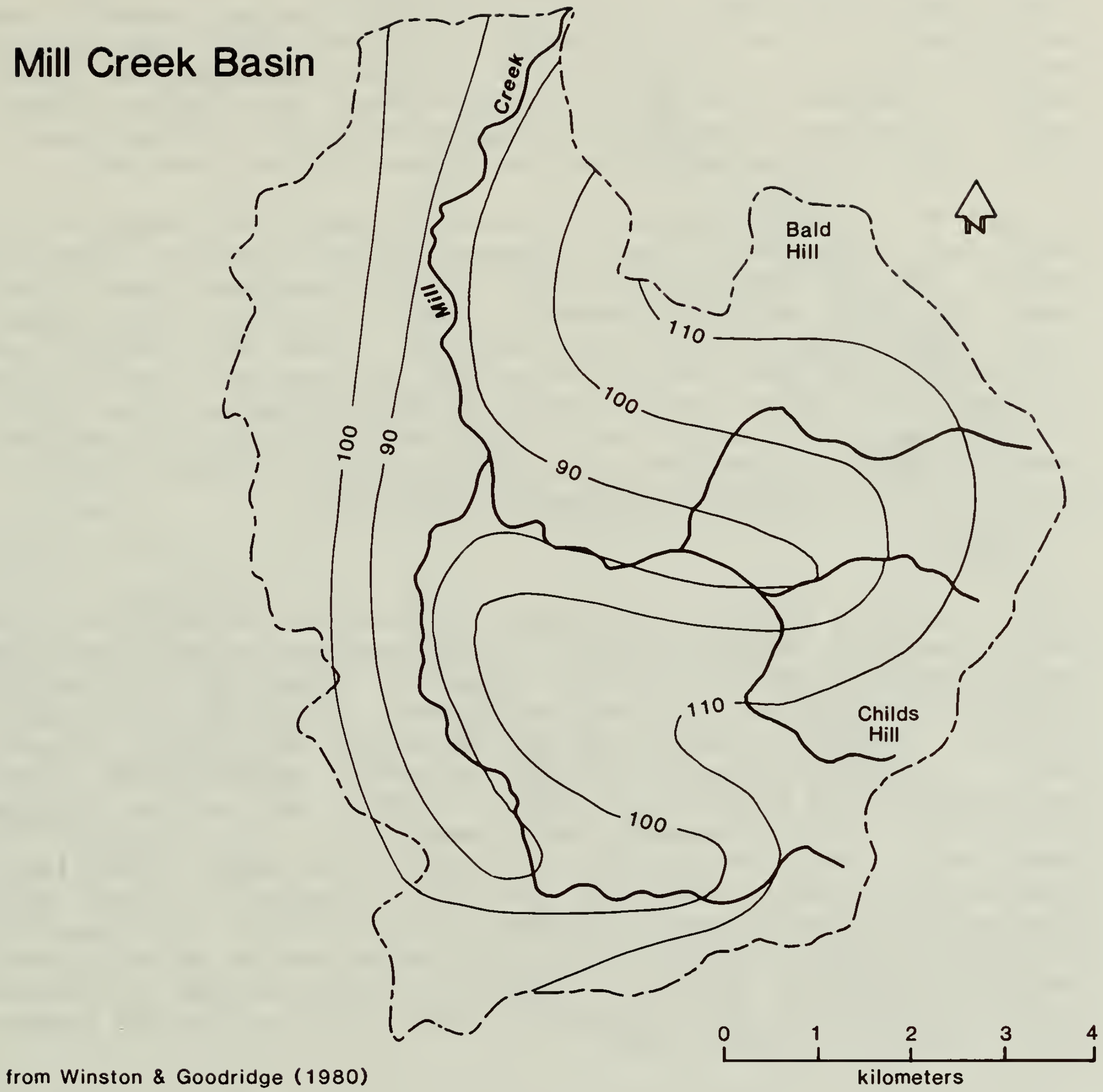


Figure 3. Isohyetal map of Mill Creek showing contour lines of mean annual precipitation (in inches).

(downstream) end of the basin. Overstory conifers associated with the coast redwood and Douglas fir forest include Sitka spruce, grand fir and western hemlock. Overstory hardwoods include red alder, madrone, tan oak, canyon live oak, giant chinquipin, bigleaf maple and California laurel. Understory species include swordfern, bush monkey flower, oxalis, coyote bush, blackberry, rhododendron, azalea, red huckleberry, salal, bush lupine and several species of manzanita and ceanothus.

The Bald Hill prairie, located on the divide between Mill Creek and the South Fork of the Smith River, supports limited overstory stands of Jeffrey pine and Douglas-fir as well as knob cone pine, Port Orford cedar and shrub tan oak. Understory species include Idaho fescue, salal, rhododendron and varnishleaf ceanothus. Poor soils derived from ultramafic rocks that crop out along the northeastern ridges of the drainage basin, support only severely stunted vegetation. The Childs Hill prairie and hardwoods area include overstory species of tan oak, giant chinquapin and madrone, while rhododendron, varnishleaf ceanothus and California huckleberry are among the understory.

C. Geology

Figure 4 shows a general distribution of rock types in the basin. The basin's geology is dominated by the 'Broken Formation' of the Franciscan Assemblage. The Broken Formation comprises tectonically fragmented interbedded graywacke, shale and conglomerate (Blake and Jones, 1974) (Table 2). Most of the sandstones and shales are classified as textural zone 1 (unmetamorphosed) although slightly metamorphosed rocks (metagraywacke and argillite of textural zone 2) crop out on the Bald Hills. The contact between these members of the Franciscan is gradational. The north-northwest trending Coast Range Thrust Fault bisects the northeast corner of the basin (Figure 4). This fault separates Franciscan Assemblage sedimentary rocks of the Coast Ranges on the west from highly sheared serpentinite and peridotite of the Klamath Mountain province on the east. Metamorphic rocks assigned to texture zone 3 (schist), and possibly texture zone 2, crop out on the eastern edge of the fault (Strand, 1963).

Table 2: Degree of Textural Reconstitution of Graywacke Sandstone (from Blake and Jones, 1974).

Textural Zone	Description
1	No foliation
2	Platy cleavage with bedding features preserved
3	Well-developed foliation largely obliterating bedding features, and quartz segradation laminae exceeding 1 mm in thickness, Units with zone 3 graywackes were formerly termed "South Fork Mountain Schist."

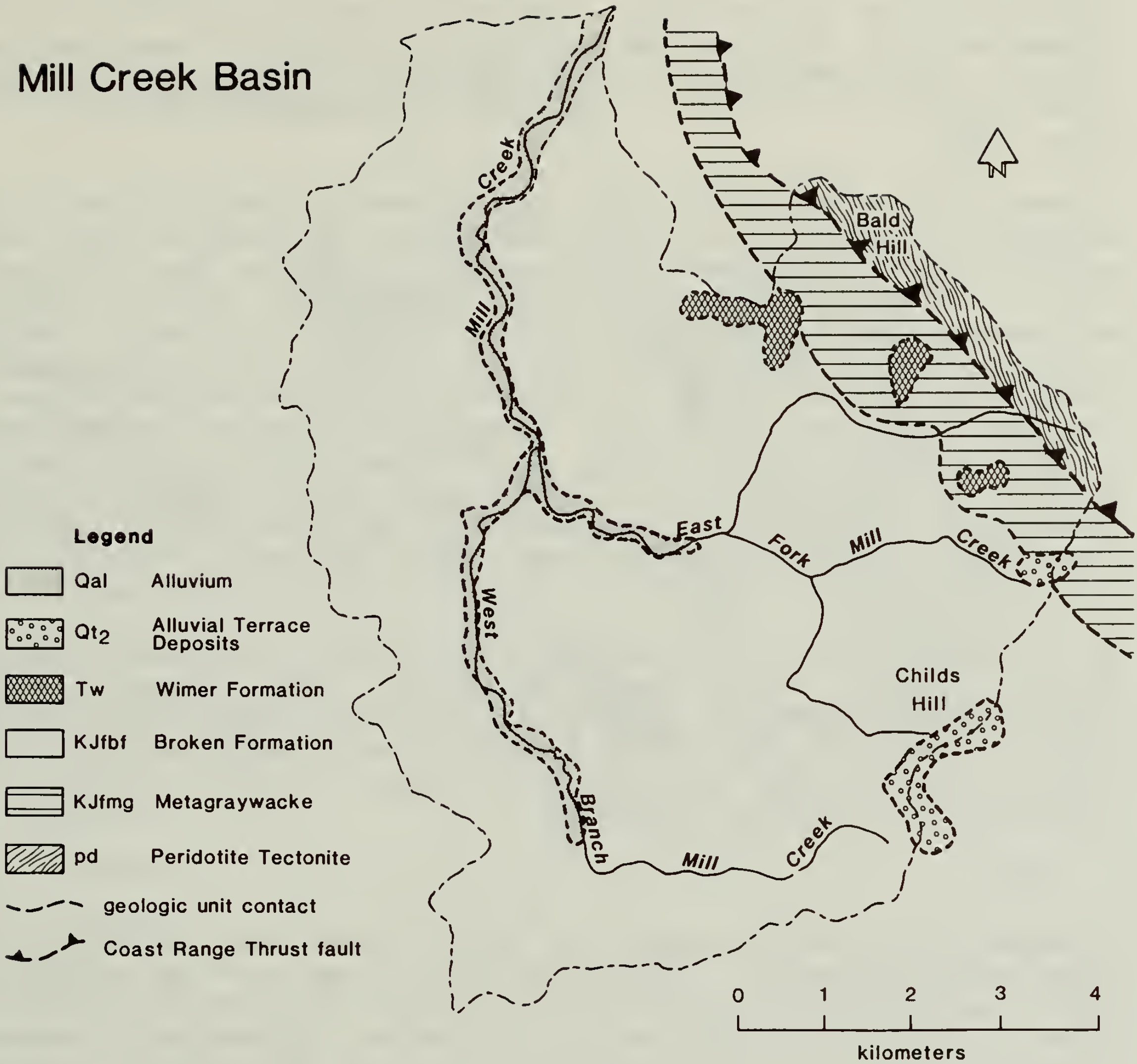


Figure 4. Geologic map of Mill Creek basin showing major bedrock units and faults.

Miocene shallow marine deposits of the Wimer Formation cap ridges in the northeastern part of the basin. Remnants of greatly uplifted alluvial terrace deposits, which contain many clasts of crystalline rocks derived from the Klamath Mountain province, emerge along ridge crests in the Child Hill area and in the central basin (Iwatsubo and others, 1976; Aalto, 1982).

Sedimentary rock units of the Franciscan Assemblage consist primarily of sandstone and mudstone with minor amounts of conglomerate, chert and volcanic rocks. A coherent sandstone unit, common in the Mill Creek basin, is characterized by a high sandstone content, massive bedding, and moderate shearing and fracturing, which results in steep, straight hillslopes (Harden and others, 1981). In contrast, much of the Redwood Creek basin in underlain by an incoherent sandstone unit which has a lower sandstone:mudstone ratio and is more highly sheared than the rocks of the coherent sandstone unit. The incoherent unit underlies a subdued, rolling landscape with less deeply incised drainage networks (Harden and others, 1981). The presence of the former unit in the Mill Creek basin is reflected in its steep rugged topography, especially in its headwater regions, and its low sediment yield (discussed later).

The tectonic history of the immediate area is poorly understood although tectonic activity is documented in adjacent areas (Carver, 1982). Preliminary data (Stephens, personal communication) suggest uplift rates may be higher than areas farther south. The suite of alluvial and strath terraces in the basin may have formed in response to changing base levels due to tectonic activity.

D. Soils

Ten named soil types were mapped in the Mill Creek basin by DeLapp and others (1977) (Figure 5). Most of the soils in the basin are moderately deep to very deep with good cohesion and support large stands of timber. Slopes on these soils range from 0 to 30 percent in the alluvial reaches to up to 75 percent in the surrounding hills, and they generally tend to have moderately high to high erosional hazard ratings (Table 3).
The predominant soil types are the Melbourne-Josephine associations which have, for the most part, formed on the slopes adjacent to Mill Creek. These soil series have a moderate erosion potential and are physically stable. Although the Bald Hill area was not mapped, serpentine and peridotite parent rock probably weathered to strongly alkaline soils (Weitchpec and Cornutt series). Otherwise, the soils are very well suited to timber production. Table 4 shows what percentage of the basin is occupied by specific soil associations, their associated slope classes, and sediment input potential based on USFS mapping (DeLapp and others, 1977).

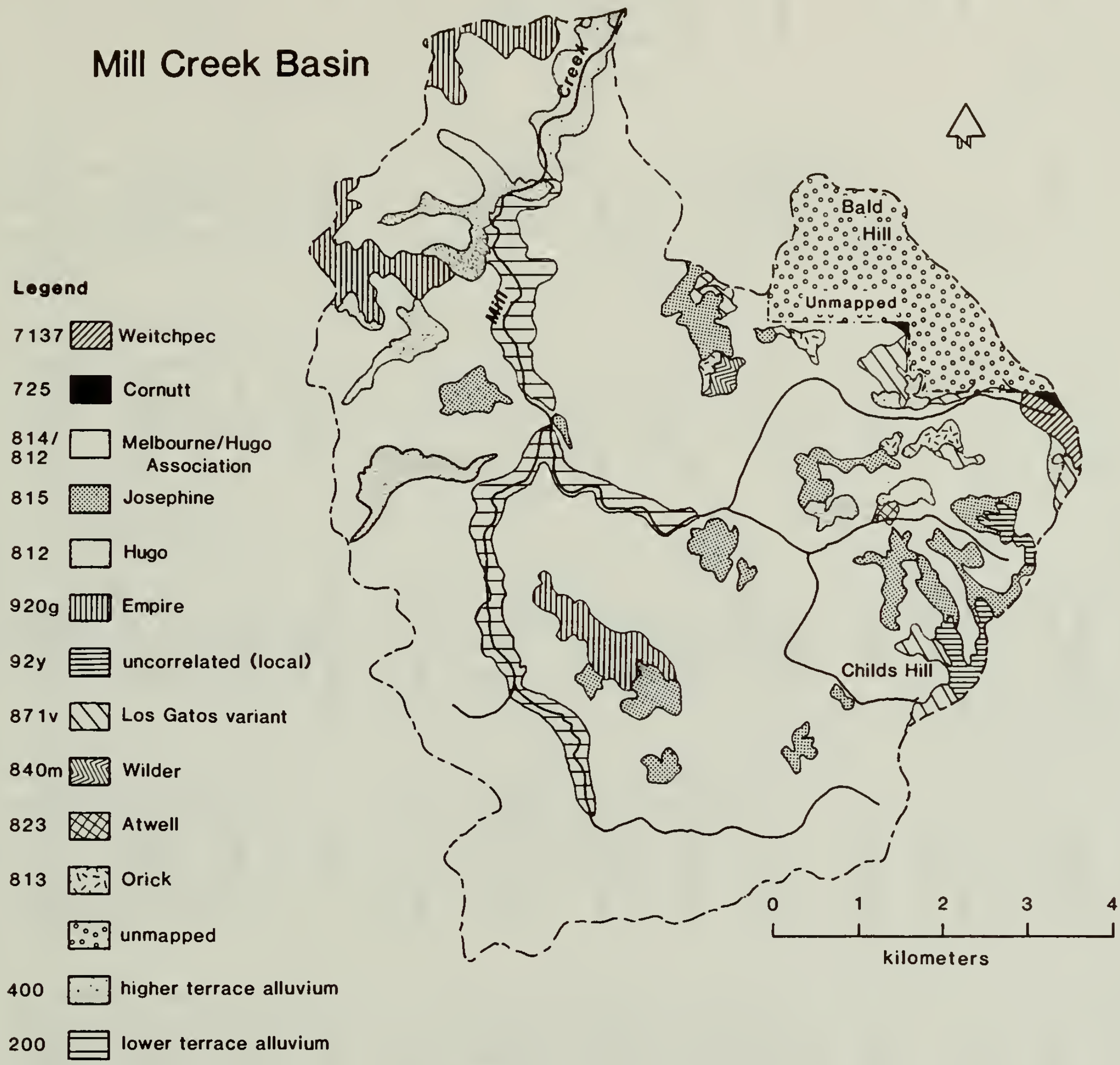


Figure 5. Soils distribution map of the Mill Creek basin.

Table 3: Selected Behavior or Characteristics and Productivity Estimates of the Predominant Soil Series in the Mill Creek Basin (USFS, 1977).

Soil Series Number	Name	Soil Depth(cm)	Permea-bility	General Drainage	Erosion Hazard	Timber	Range
812	Hugo	75 - 180	mod. to rapid	well to excessive	very high	med. to high	low to unsuited
813	Orick	150 - 300	moderate	well	high	low to medium	very low
814	Melbourne	115 - 200	moderate	well	moderate	med. to v. high	medium
815	Josephine	50 - 150	moderate	well	mod. to high	high	medium to low
920g	Empire	100 - 180	moderate	well	mod. to high	high	medium to low
871v	Los Gatos (var.)	50 - 90	mod. slow	well	mod. to v. high	unsuited	unsuited
7137	Weitchpec	75 - 130	mod. rapid	well to excessive	high	unsuited	unsuited
823	Atwell	90 - 150	slow	somewhat poor	mod. to high	medium	medium
725	Cornutt	50 - 130	slow	well	mod. to high	medium and high	v. low to unsuited
840m	Wilder	30 - 150	rapid	well to excessive	moderate	medium	low to very low
92y	Unnamed	75 - 150	mod. rapid	well	moderate	unsuited	very low
200	alluv.terr.	-----	----	----	----	-----	------
400	higher alluv.terr.	-----	----	----	----	-----	------

Table 4: Distribution of Major Soils in the Mill Creek Watershed

Soil Type	Potential Sediment Input	Percent of Watershed
Deep Melbourne, Hugo and Josephine soils on moderately steep slopes (30-50%).	Moderate to slight (unless surface runoff is concentrated; then is subject to deep gullying)	43.1
Deep Melbourne and Josephine soils on gentle slopes (less than 30%).	Slight	13.7
Soils on recent alluvial flats (nearly flat).	Slight	8.0
Deep Empire soil on gentle slopes (less than 30%).	Slight (unless surface runoff is concentrated; then is subject to deep gullying)	8.0
Moderately deep, stony Melbourne, Hugo, Josephine and Orick soils on steep slopes (50-70%).	High (when cover is severely disturbed, and surface runoff is concentrated)	22.7
Shallow, very stony Hugo soils on very steep slopes (greater than 70%)	High (subject to loose debris slides, and severe gullying in skid trails)	4.5
Moderately deep Atwell soil	Very high (subject to debris slides)	<1.0

E. Physiography

The Mill Creek drainage basin consists of high relief, intricately dissected terrain. Elevations range from 21 m, at the confluence of Mill Creek and the Smith River, to 710 m in the basin's rugged southeastern corner. Average hillslope gradients range from 18 to 20 degrees.

Drainage divides between major tributary valleys are broad and gently sloping, but away from these ridges hillslopes exhibit straight or

convex-upward profiles and steep gradients that frequently exceed 25 degrees. Broad flat valley bottoms abut directly against the hillslopes, and throughout most of the basin these valley bottom flats represent the active floodplain. However, for much of its lower reach (from 0.8 km below the confluence of the West Branch and East Fork downstream to the backwater deposits of the Smith River) Mill Creek flows through a narrow bedrock channel incised five to ten meters into a broad strath terrace (Iwatsubo and others, 1976).

Drainage basin shape is nearly circular, with a slight elongation in a northerly direction. The overall channel pattern is dendritic, although parts of the basin display a weakly trellised pattern, and some tributaries display abrupt right angle bends. Channel gradients are regular and moderately steep (2.5 to 6.4%), with local gradient irregularities associated with concentrations of coarse organic debris. Figure 6 is a longitudinal profile of Mill Creek based on topographic maps. Channel bed material ranges from sand to cobbles with occasional boulders.

Table 5 (adapted from Iwatsubo and others, 1976) compares physical characteristics of portions of Mill Creek with those of Redwood Creek. Relief is simply the difference between the highest and lowest elevations in the basin. The relief ratio is drainage basin relief divided by the length of a straight line from the mouth to the high point on the divide. A hypsometric curve shows the proportions of a basin at various altitudes above the mouth of the basin. The area under the hypsometric curve provides an index for basin geometry. High values indicate that hillslope gradients are lowest near the divides and become steeper toward the channels. Low values imply high hillslope gradients near divides with lower gradients near channels. The elongation ratio is the ratio of the diameter of a circle divided by the maximum length of basin measured in the direction of basin aspect.

Tributary channels in Redwood and Mill Creeks have the highest relief ratios and the highest hypsometric values. Profiles for these streams are highly concave upward and hillslopes are very steep near divides. Average hillslope gradients are slightly higher for Mill Creek than for the Redwood Creek basin. Drainage densities are similar for all basins in this study. Stream gradients decrease with increasing drainage area. The Redwood Creek basin is more elongated than the Mill Creek basin; however, both mainstems are sixth-order streams. These drainage basin characteristics will be further discussed in the sediment yield section.

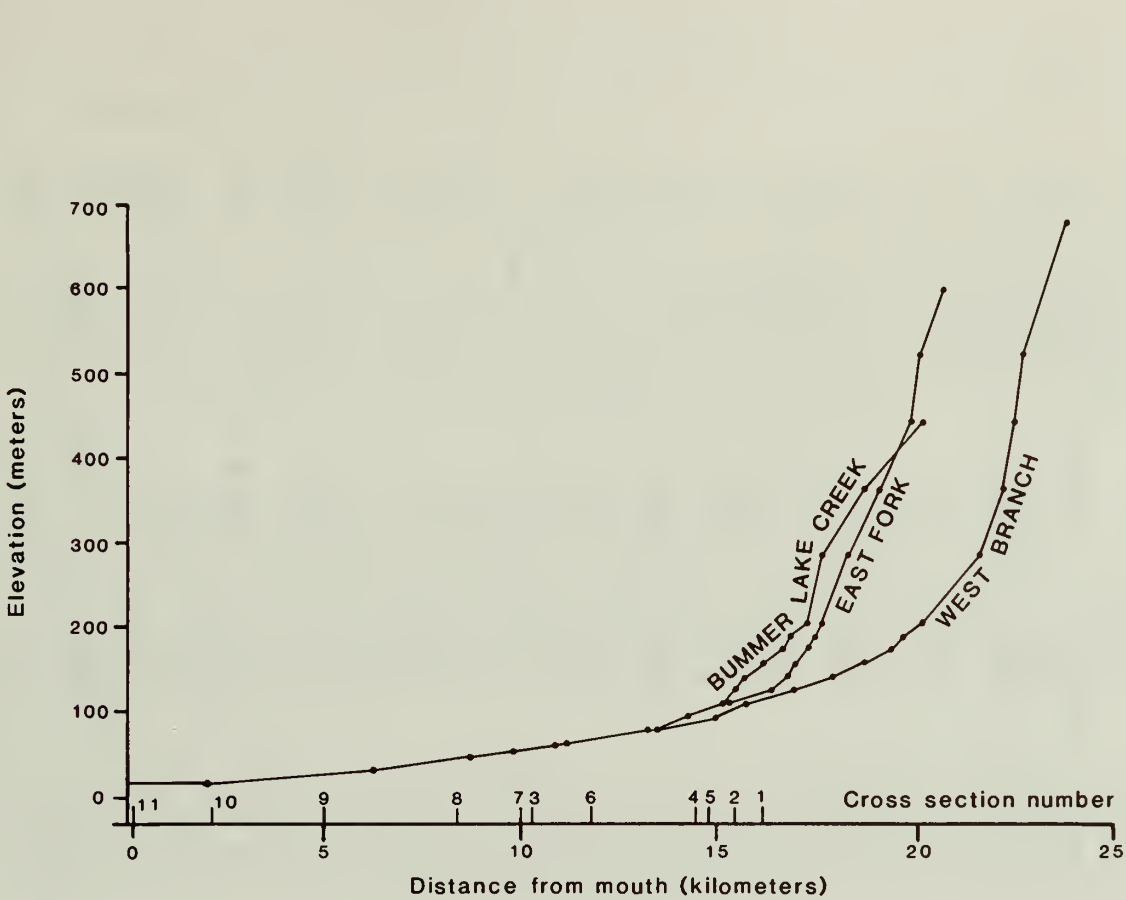


Figure 6. Longitudinal profile of Mill Creek and its major tributaries showing locations of cross sections.

Table 5: Physiographic Characteristics of Mill and Redwood Creeks

Station	Drainage Area (km^2)	Relief (m)	Relief Ratio (m/m)	Area Under Hyposemetric (in^2)	Average Slope (deg.)	Drainage Density (km/km^2)	Average Stream Gradient (m/m)	Elong. Ratio	Stream Order
West Branch Mill Creek near Campground	17.9	575	.10	10.97	20.0	4.82	.064	.69	5
West Branch at Bridge	28.0	610	.08	9.72	19.0	5.35	.045	.59	5
East Fork Mill Creek	43.3	640	.10	10.47	20.0	4.55	.045	.74	5
Mill Creek at gage	74.1	650	.09	10.32	19.0	4.53	.038	.77	6
Mill Creek at bridge	90.9	670	.07	9.48	19.0	4.53	.027	.85	6
Mill Creek at mouth	99.7	690	.06	9.93	18.0	4.53	.025	.80	6
Redwood Creek near Blue Lake	175	1350	.05	7.54	12.4	5.47	.031	.60	5
Redwood Creek at Panther Creek	389	1500	.03	6.56	16.2	5.28	.019	.46	6
Redwood Creek at old South Park Boundary	479	1550	.03	6.55	14.0	2.98	.019	.43	6
Redwood Creek at Orick	720	1600	.02	5.37	14.4	4.79	.013	.38	6
Copper Creek	7.20	850	.19	8.33	18.8	4.85	.180	.67	4
Lacks Creek	44.00	1100	.08	7.70	18.3	5.66	.060	.63	5
Little Lost Man Creek	8.96	650	.10	8.94	17.7	3.85	.080	.52	4

III. LAND USE HISTORY

A. Ownership History

As early as the 1850's timber was harvested in the Mill Creek basin and was milled in Crescent City at Del Norte County's first established mill. Later W. Bayse built and operated a water-powered mill on Mill Creek (Bearss, 1969). Logging continued sporadically into the early 1900's, when Hobbs, Wall and Company began logging the western slope of Howland Hill and the northwestern hills of the Mill Creek watershed. They used steam donkeys (steam engines) to yard the logs and the Del Norte and Southern railroad to transport the timber to mills (Bearss, 1969).

In 1920 Hobbs, Wall and Company established a logging camp on Mill Creek near the present site of Miller-Rellim Redwood Company's Mill Creek nursery. A railroad spur connected the camp to Crescent City. Three inclined railways were built on steep slopes, enabling the company to access timber in the upper watershed. Hobbs, Wall and Company went out of business in 1939 and was acquired by Miller-Rellim (Steve Veirs, personal communication).

In 1929 the Frank D. Stout Memorial Grove was established when 17.8 ha were given to the State of California by Stout's family. Mill Creek Redwoods Park was created in 1944 by Save-the-Redwoods League. This tract consisted of 3760 ha and became part of the larger Jedediah Smith Redwoods State Park in 1951 (Bearss, 1969).

Beginning with private gift-deeds in 1924 and followed by successful campaigns of the Save-the-Redwoods League through 1942, Del Norte Redwoods State Park was established and expanded to 2580 ha. Today, the west side of the Mill Creek watershed is included in this park. In all, 39.0 km^2 (3900 ha) of the basin are under state and federal ownership. Figure 7 shows the present-day distribution of land ownership in Mill Creek.

B. Timber Harvesting Practices

The history of timber harvesting practices is well represented in the Mill Creek basin. Before the advent of crawler tractors in the late 1930's, steam donkeys were used to log timber. This method employed a cable system where the yarding machinery was hauled from ridge to ridge along specially constructed rail routes. It differs from later forms of timber harvest in that less road construction was required (Best, 1984).

Janda and others (1975) used aerial and ground photographs from other nearby areas to evaluate the erosional impact of early steam donkey yarding. These studies indicate that early steam donkey yarding techniques resulted in large clear-cut areas, heavy concentrations of slash and intense localized ground disturbance surrounding landings and skid trails. However, surface drainage patterns were altered much less than by large scale tractor-yarded clear-cuts typical of later years (Best, 1984).

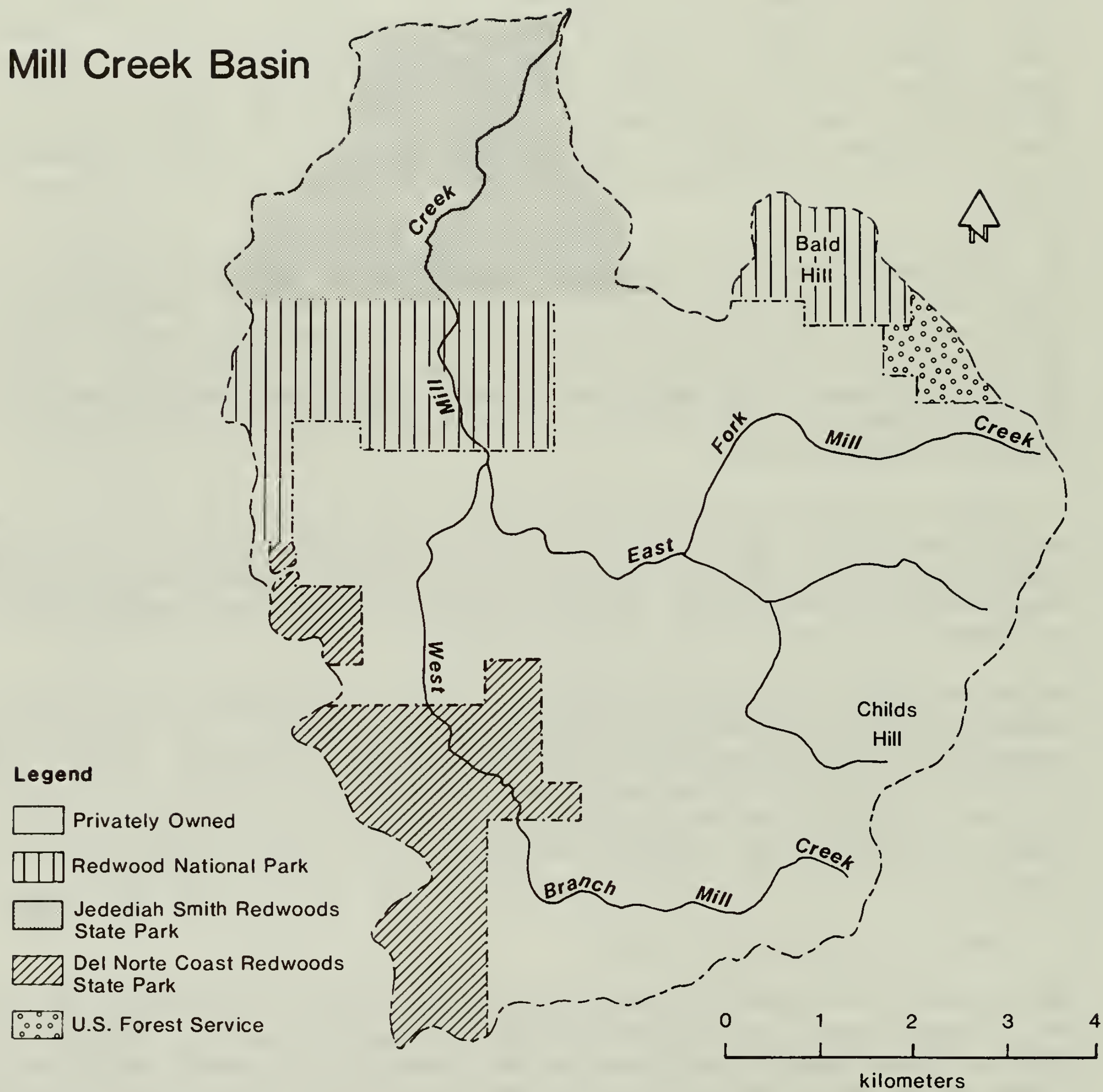


Figure 7. Map of Mill Creek basin delineating ownership boundaries.

With the introduction of the crawler tractor, seed tree leave and selection cutting were possible, and timber harvest that left a considerable portion of standing trees became common. Tractor yarded areas where a substantial portion of the stand was left uncut has been referred to as selectively cut (Janda and others, 1975); however, the term "seed tree leave" cut is more appropriate. By definition, selection cutting is a practice where trees are removed as they reach maturity (Smith, 1962). It is used in all-aged silvicultural management where the forest is managed to have many ages of trees represented in the stand. Since the forests of the Mill Creek watershed were essentially at maturity prior to logging, selection cutting never really occurred.

In seed tree leave cutting, the majority of the stand is removed during the first harvest operation, and only trees with sufficient cone production to assure restocking of the area are left uncut (Smith, 1962). Aerial photographs show that in many of the early harvest areas in the Mill Creek basin at least 70 percent of the volume of the original cut was harvested, which clearly indicates a seed tree leave management practice (Stone and others, 1969). For the sake of brevity in this report, 'seed tree leave method' will be referred to as partial cutting.

During the early 1950's, when partial cutting was the most common method of harvesting and restocking the redwood forests, timber companies became more proficient with crawler tractors and other equipment capable of handling massive redwood logs and concomitantly increased their inventories of these machines (Janda and others, 1975). Over the next decade, clear-cutting became the most dominant method of logging. The use of larger cut blocks, tractor-constructed lay outs (smooth beds of dirt onto which trees were felled to reduce stem breakage), and increased reliance on tractor yarding also increased. Adjoining blocks of timber were harvested in successive years to minimize the costs associated with road construction and maintenance. The procedure resulted in much larger contiguous cut blocks and areas of exposed mineral soil.

By the late 1960's, partial cutting was almost completely replaced by clear-cutting in the Mill Creek watershed. Foresters had observed that residual trees did not experience the rapid release of growth that was anticipated following original thinning of the stand (Janda and others, 1975). Additional reasons cited by the timber companies include severe stem breakage suffered by residual trees toppled during major wind storms, and inefficiency and poor reliability of using trees to restock cut areas (Janda and others, 1975).

Although tractor yarding was, and continues to be, the preferred clear-cutting method, cable yarding systems are used in parts of the watershed where slopes are greater than 40 percent. Cable yarding is a system by which logs are yarded to a landing site by a machine equipped with multiple winches called a yarder (Studier, 1984). In the Mill Creek basin, skyline cable yarding methods are used to bring the felled timber from a point on the slope to the top of the ridge or to an

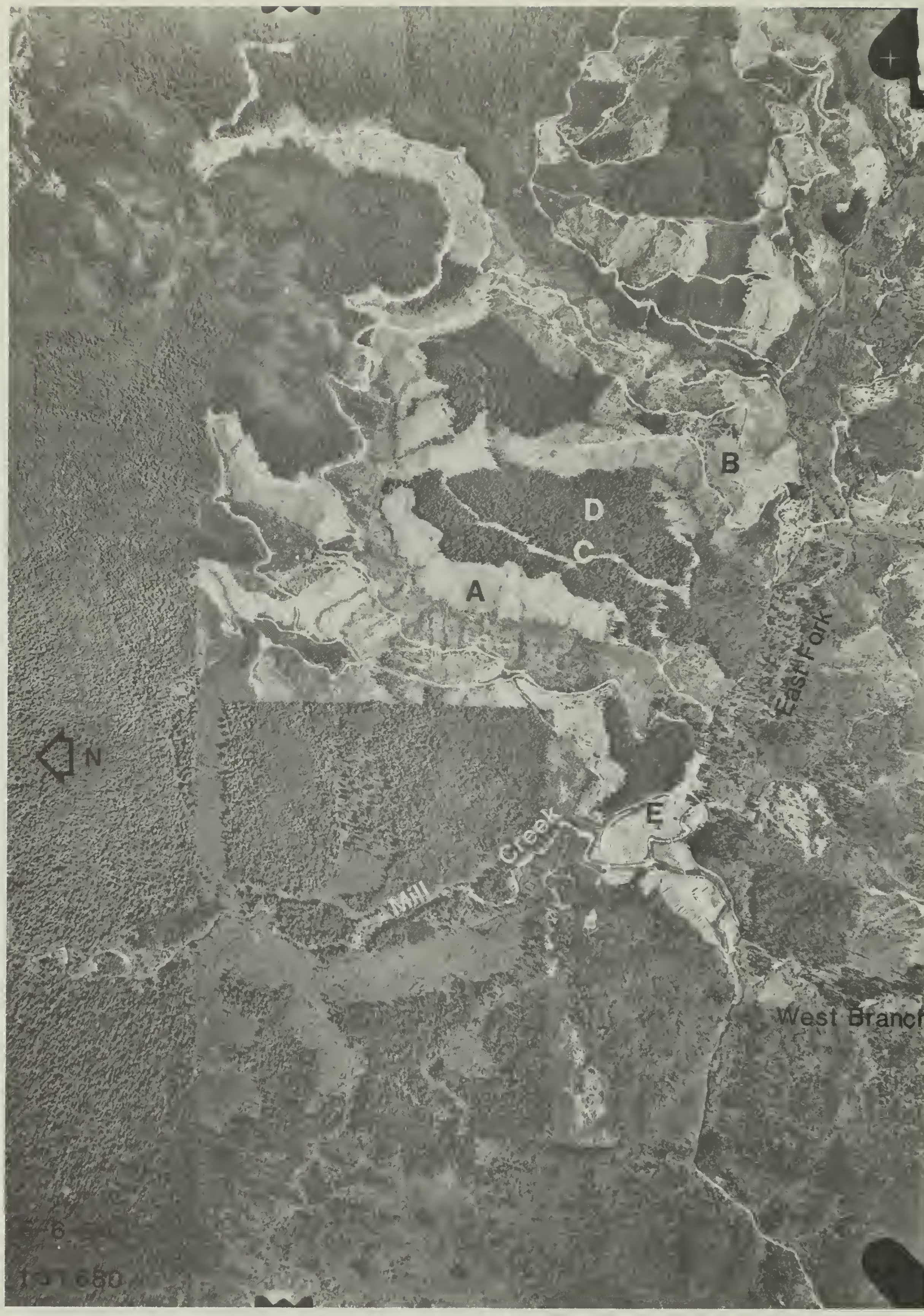


Figure 8. Overview of Mill Creek basin showing cable-yarded unit (A), tractor-yarded clearcut unit (B), haul roads (C), old-growth forest (D), and Miller-Rellim Timber Company's mill site (E).

upslope logging road. This allows large areas to be yarded with minimal site disturbance and low road density. Cable systems are limited to clear-cut logging since the overhead cable usually damages or destroys most remaining vegetation two to three meters in height (Best, 1984).

C. History of Timber Harvest

Because over 69 percent of the Mill Creek watershed is held in private ownership, this report also discusses the land use history of the basin. Timber harvest and associated road construction have been and continue to be the primary activities on private lands.

Aerial photographs from 1958, 1966, 1975, and 1984 were used to compile logging history and land use maps (Figure 8). The maps were prepared by reviewing 1:24,000 scale aerial photographs in sequence and by tracing cutblock boundaries onto mylar overlays. Discrepancies in photo scales were corrected and transferred to a 1:24,000 USGS topographic base.

A logging history of the basin was constructed by delineating old- and second-growth blocks, recently logged areas and prairies for each period of review. Recently logged areas were further broken by method of yarding, type of cut (i.e. clear-cut) and the road construction associated with each cut block.

The following section provides a chronological and cumulative history of logging in the basin.

1. Pre - 1935 Timber Harvest

A large area (10.6%) of the basin contains advanced second growth, resulting from timber harvest prior to 1935. Advanced second-growth stands are located primarily along the west side of the West Branch north to Jedediah Smith Redwoods State Park. Areas east of the West Branch along two kilometers north and south of Del Norte Redwoods State Park were also logged. A total of 1058 hectares (ha) were harvested, probably using steam donkeys to yard logs (McKenna, Del Norte County, personal communication) (Figures 9 and 10).

2. 1935-1958 Timber Harvest

Between 1935 and 1958 tractor yarding became the dominant logging method in the Mill Creek watershed. An additional 1134 ha (11.37% of the basin) were logged, predominantly in the south-central and southeast portions of the basin. Of this hectarage, 624 ha were partially cut and 510 ha were clear-cut, using both tractor and cable yarding methods (Figure 9 and Table 6).

During this period, 36 ha were cleared around the confluence of the West Branch and East Fork of Mill Creek. A sawmill and veneer plant were constructed on the site, with future plans for a chip-board plant (Stone and others, 1969).

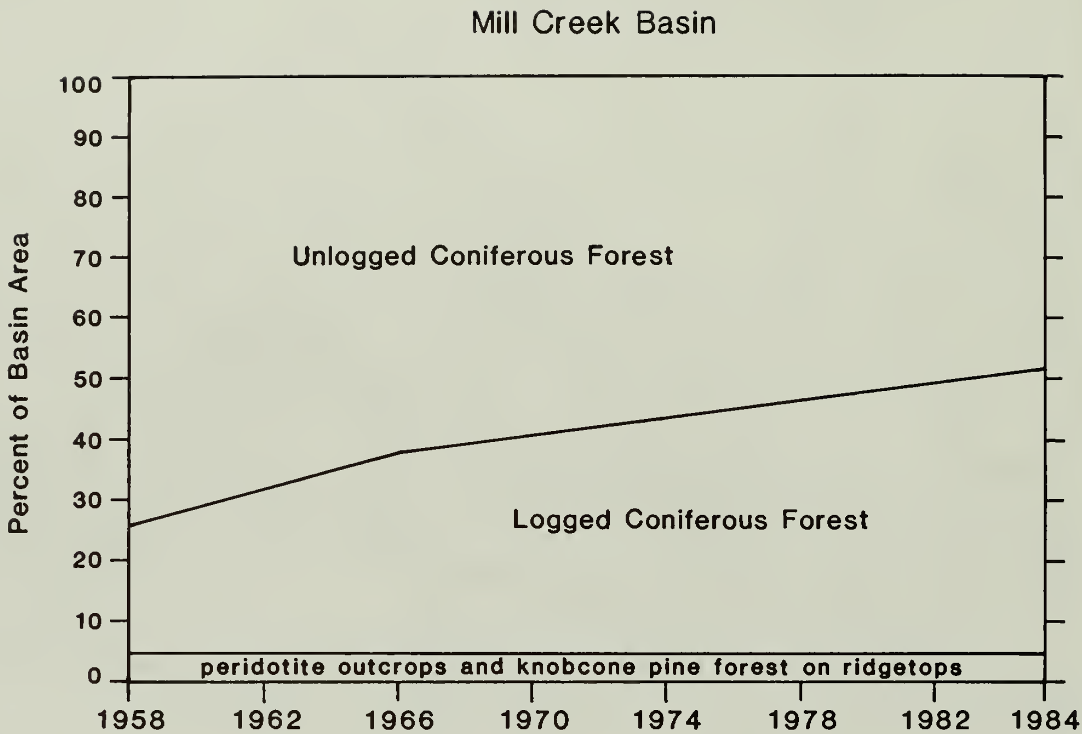


Figure 9. Summary of timber harvest history in Mill Creek basin.

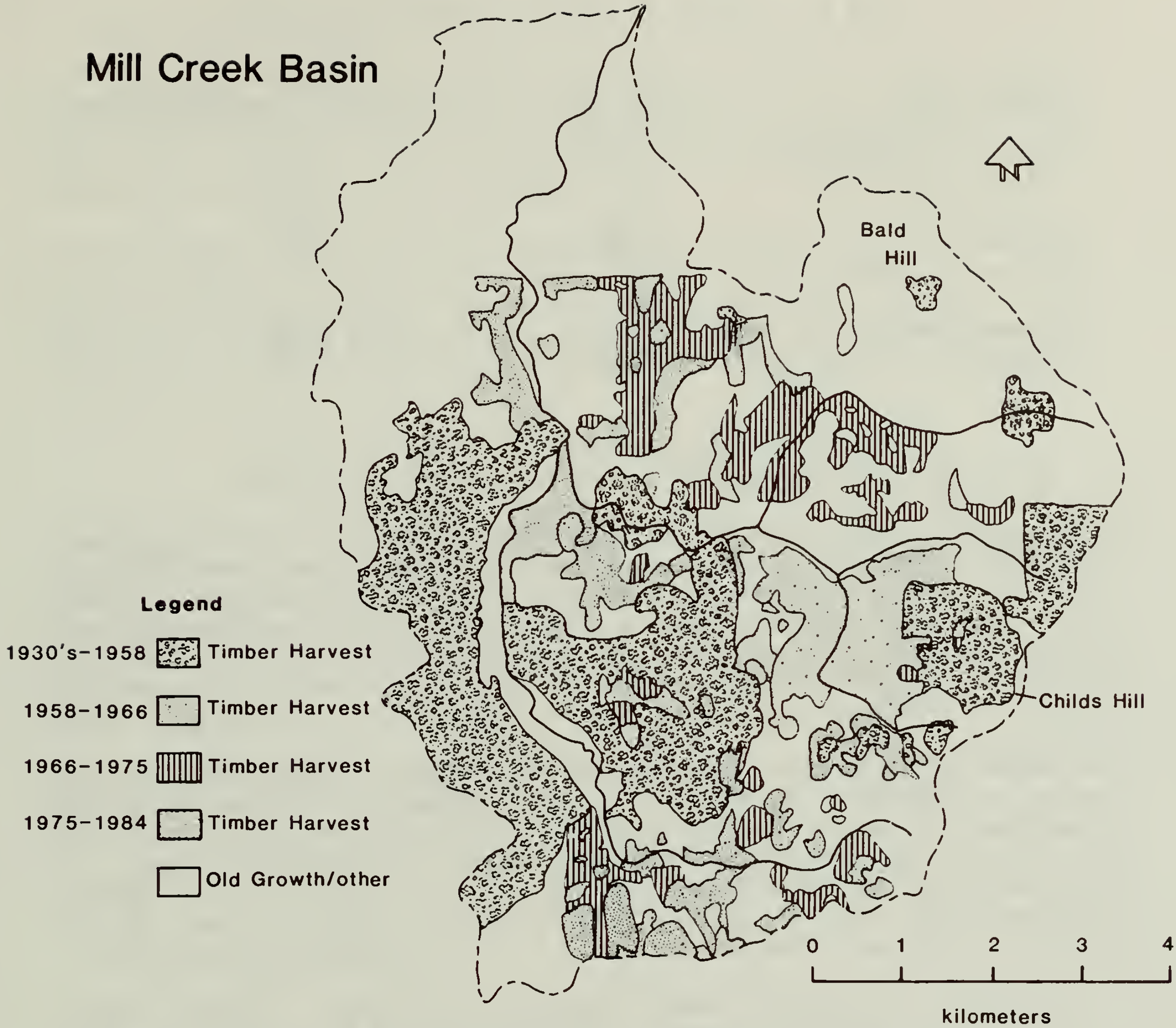


Figure 10. Map of timber harvest units in Mill Creek basin.

Table 6: Summary of Timber Harvest as of 1958 in the Mill Creek Basin (A = 99.7 km²)

Type of Cut	Area (ha)	Percent of Total Basin Area
Clear-cut (tractor)	369	3.70
Clear-cut (cable)	141	1.41
Partial cut	624	6.26
Total	1134	11.37
(re-entry cuts)	--	--
Logged Areas as of 1935	1058	10.61
Cumulative Total	2192	21.98

3. 1958-1966 Timber Harvest

Clear-cutting timber harvest by both tractor and cable yarding methods continued to dominate logging practices in the Mill Creek basin between 1958 and 1966. Although most of the clear-cutting occurred in the southern half of the watershed, a substantial block of old-growth west of the mainstem of Mill Creek in the central part of the basin was harvested. By 1966 a total of 657 ha were logged using these methods (Table 7).

The majority of partial cutting occurred in the south-central basin, south of the East Fork of Mill Creek. Smaller blocks were cut throughout the central and southern basin. During this time period, 86 ha of old cuts were re-entered and logged for remaining timber. A total of 1125 ha (11.28% of the basin) were harvested for timber (Figure 9 and Table 7), the largest volume of timber per year of the four time intervals studied.

Table 7: Summary of Timber Harvest as of 1966 in the Mill Creek Basin (A = 99.7 km²)

Type of Cut	Area (ha)	Percent of Total Basin Area
Clear-Cut (tractor)	374	3.75
Clear-Cut (cable)	283	2.84
Partial Cut	382	3.83
Total	1039	10.42
(re-entry cuts)	(86)	(.86)
Logged Areas to 1958	2192	21.98
Cumulative Total (minus re-entry cuts)	3231	32.40

4. 1966-1975 Timber Harvest

Until 1966, the majority of timber was harvested south of Mill Creek's East Fork and west of the mainstem. In the years between 1966 and 1975 large tracts of clear-cuts were completed north and northwest of the East Fork. Extensive clear-cutting also occurred east of the mainstem and south of the state park boundary.

Of the 798 ha of timber that was clear-cut during this time period, 393 ha were cable-yarded and 405 ha were tractor-yarded. Only 9 ha were harvested using the partial cut method, while 28 ha were re-entry cuts (Table 8). By 1975 almost 40 percent of commercial timber had been harvested in the Mill Creek basin (Figure 9).

Table 8: Summary of Timber Harvest as of 1975 in the Mill Creek Basin (A = 99.7 km^2)

Type of Cut	Area (ha)	Percent of Total Basin Area
Clear-Cut (tractor)	405	4.06
Clear-Cut (cable)	393	3.94
Partial Cut	9	.09
Total	807	8.08
(Re-entry cuts)	(28)	(.28)
Logged Areas to 1966	3231	32.40
Cumulative Total (minus re-entry cuts)	4038	40.48

5. 1975-1984 Timber Harvest

By 1975, partial cutting as a timber harvest method was completely abandoned in favor of clear-cut logging. Much of the harvest activity was concentrated in the north- and south-central basin on either side of Mill Creek's East Fork. Many smaller tracts were harvested in the southern basin, where old cuts were re-entered to remove remaining old-growth trees. The larger tracts were confined to areas adjacent to the lumber mill, where good access roads were available.

A total of 676 ha were harvested from 1975 to 1984, all by clear-cutting (Table 9). This represents a little over six percent of the basin which brings the cumulative total of logged area to 46.8 percent to date (Figure 9).

Table 9: Summary of Timber Harvest as of 1984 in the Mill Creek Basin (A = 99.7 km²)

Type of Cut	Area (ha)	Percent of Total Basin Area
Clear-Cut (tractor)	347	3.48
Clear-Cut (cable)	279	2.80
Partial Cut	---	---
Total	626	6.28
(Re-entry cuts)	(24)	(.24)
Logged Areas to 1975	4038	40.48
Cumulative Total (minus re-entry cuts)	4664	46.76

6. Percent of Harvest on Private Lands

Federal and state park agencies manage 39.0 km² of the Mill Creek basin and have protected the lower basin from timber harvest. Table 10 shows the area of privately held land that has been logged for each of the time periods under study. Timber harvests prior to 1935 are not included because these lands were subsequently acquired for park land. Nearly 60 percent of the total hectarage in private ownership had been logged by 1984.

Table 10: Summary of Timber Harvest on Privately Owned Land in the Mill Creek Basin (A = 60.7 km²)

Period	Area (ha)	Percent of Total Basin That is Privately Owned
1935-1958	1134	18.68
1958-1966	1039	17.12
1966-1975	807	13.29
1975-1984	626	10.31
Total	3606	59.40

7. Summary of Land Use

Logging is the dominant land use in the Mill Creek watershed. Early timber harvesting was concentrated in the western basin, probably using steam donkeys. By the latter part of the 1930's, crawler tractors replaced steam donkeys as yarding machines and partial cut harvesting became the dominant method. The most intensively logged period in the Mill Creek basin was 1958-1966, with activity concentrated in the southern and central areas of the watershed. By the late 1960's, clear-cutting became the dominant harvesting method and logging in the basin moved into areas north and northwest of Mill Creek's East Fork.

Timber harvest by cable yarding increased at a faster rate than other methods, indicating that steeper slopes were being harvested. From the mid-1970's to 1984, timber harvesting slowed somewhat and the clear-cut method was used exclusively in the basin. By 1984 almost 50 percent of the watershed had been logged (Figures 9 and 10).

D. Road Construction

In this report, roads are classified as either paved roads or major haul roads, including county and jeep roads. Road lengths in the Mill Creek watershed were measured for 1958, 1966, 1977 and 1984. Aerial photographs from these dates were used in conjunction with 1964 USGS topographic maps to determine road lengths. The 1958 road lengths were measured using aerial photographs at a scale of 1:24,000. The 1966 road lengths were measured using a USGS topographic base map, and checking this against 1966 1:12,000 aerial photographs. The 1977 roads were measured from 1:32,500 U-2 photographs, and 1984 road lengths were taken from 1984 1:30,000 aerial photographs. Table 11 shows road lengths for each time interval and Figure 11 illustrates the progression of road-building in the basin. Table 11 shows that most major haul roadbuilding took place between 1958 and 1977. This corresponds to the most active timber harvest periods. The length of paved roads has remained unchanged since 1966.

Table 11: Road Construction in the Mill Creek Basin

Time Interval	Road Type	Length (km)	% of Total Road Length
1930's-1958	paved	14.04	7.30
	major haul	56.64	29.44
1958-1966	paved	5.64	2.93
	major haul	43.47	22.59
1966-1977	paved	---	---
	major haul	52.26	27.16
1977-1984	paved	---	---
	major haul	20.35	10.58

Total paved roads: 19.68 km

Total major haul roads: 172.72 km

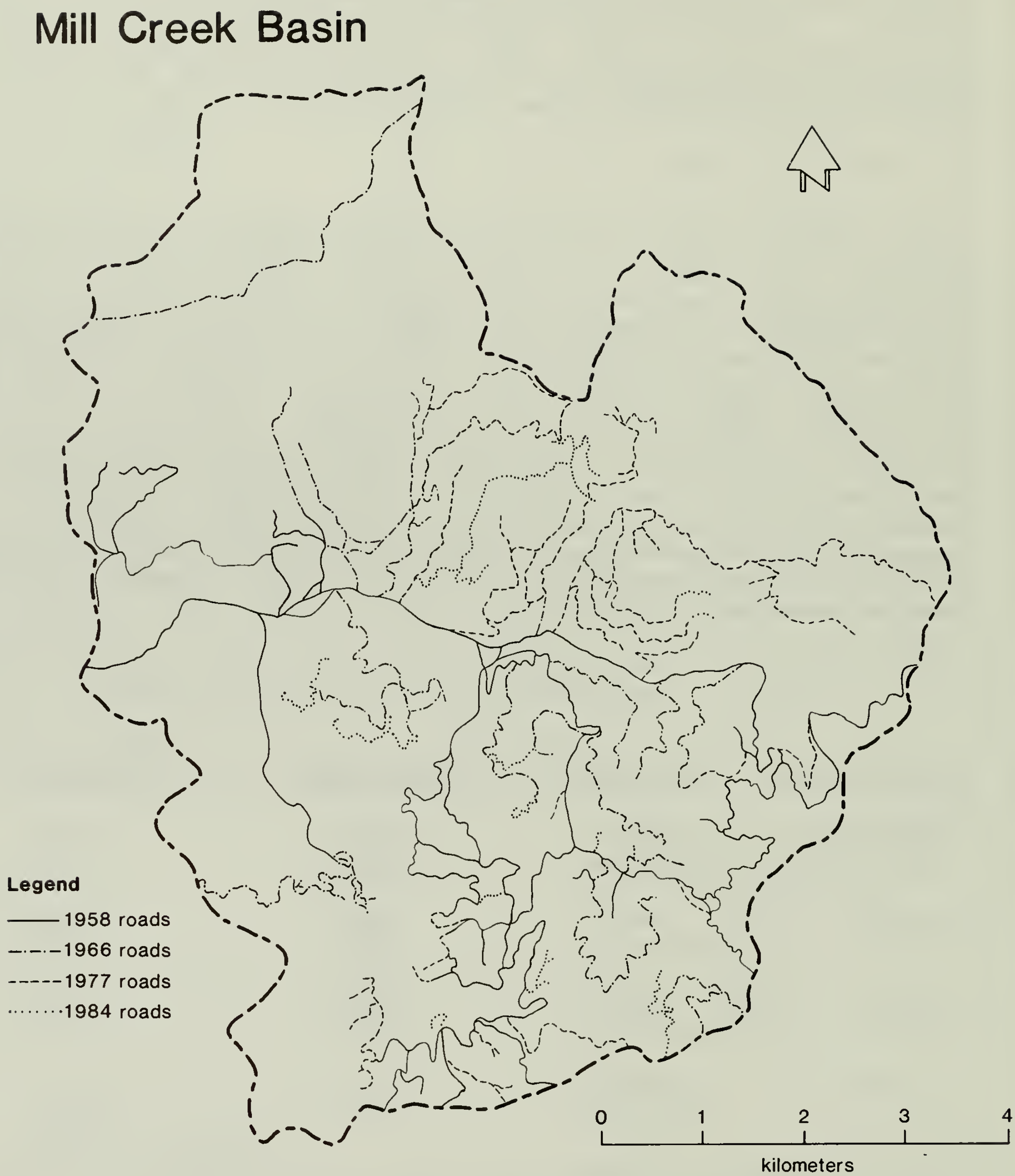


Figure 11. Map showing locations and time periods of construction for paved and major haul roads in the Mill Creek basin.

IV. EROSIONAL FEATURES

A map of erosional features in the Mill Creek basin (Figure 12) was adapted from a map by Iwatsubo and others (1976). They used 1:10,000 black and white aerial photographs from 1972 and 1975 and 1:32,500 photographs taken in 1974 to map large erosional features. In the present study we updated the map by using 1984 black and white aerial photographs enlarged to 1:12,000, and color infrared photographs at a 1:12,000 scale. The mass movement nomenclature is that used and explained by Nolan and others (1976).

There are several limitations in a study of this kind. Small scale fluvial and mass movement erosion is common throughout the watershed, but cannot be depicted at the scale used in Figure 12. In addition, mapping was restricted to features that existed at the time the photographs were taken. If a road failed or a road crossing on a stream washed out and was repaired before the photo flight, sediment contributed by these sources would be undetected in the air photo analysis. Many of the roads were constructed after 1977, and as of 1984 they had not been subjected to a large storm. Because most road-related erosional problems develop during large storms (5-year event or larger), the potential for further erosion may be present but is not quantifiable at this time. Finally, in some areas second-growth vegetation obscures the ground surface and without field checking, small slope stability problems go undetected in the air photo analysis. However, Kelsey and other (in press) showed that 95% of landslide volume in Redwood Creek was contributed by less than half of all slides; that is, the biggest slides were the major sediment sources. This relationship is probably true for Mill Creek suggesting that erosionally significant slides can be seen on the aerial photographs used for this study. Volumes of sediment contributed by slides and gullies were not computed because the depth of erosion features could not be measured accurately from the air photos and access was not available to check volume estimates in the field.

Furbish (1981) showed that most landslides in north coastal California occur downslope of major breaks-in-slope or in topographic hollows, with 95% of the landslides occurring on slopes >30 degrees. The average ground slope in Mill Creek (Table 5) ranges from 18 to 20 degrees, and less than 30% of the basin has slopes greater than 30 degrees.

Slope failures in Mill Creek, as elsewhere, occur when the driving force exceeds the shear strength of slope material. Soil cohesion, a major component of soil shear strength, decreases after logging due to the decay of roots (O'Loughlin and Zeimer, 1982). During storms pore water pressures increase. The combination of decreased cohesion and increased pore water pressure can lead to slope weakening and eventually to slope failure.

Based on the air photo analysis, fewer landslides are present in the Mill Creek basin than in the Redwood Creek basin to the south. Mill

Creek exhibits wider valleys, and fewer incised stream gorges. In contrast, landslides in the Redwood Creek basin occur most commonly on steep inner gorge slopes where the stream abuts directly against the base of hillslopes. Also, much of Mill Creek is underlain by coherent sedimentary rocks which are less likely to experience slope failure than the more sheared, incoherent rocks found in Redwood Creek. Landslides in Mill Creek are somewhat more common on slopes with an eastern aspect, especially on the West Branch of Mill Creek. Many landslides, gullies and debris avalanches identified on the photographs are associated with timber harvest and related roads.

Mill Creek Basin

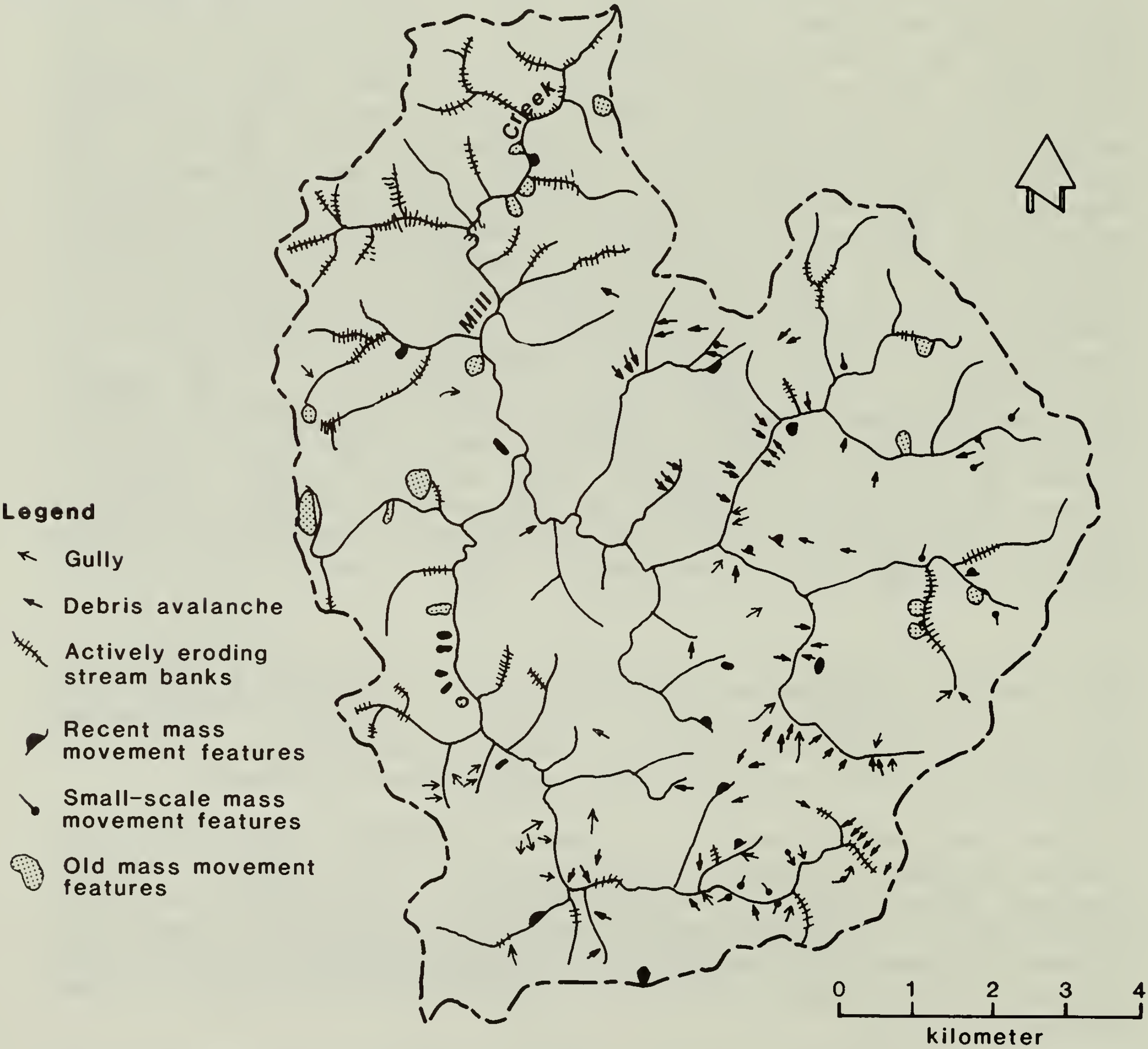


Figure 12. Map of old and recent erosional features in the Mill Creek basin.

V. CROSS-SECTION SURVEYS

A. Methods and Terminology

A technique commonly used to measure stream channel changes is a cross section surveyed between two permanently mounted end points (Emmett, 1974). Annual surveys determine changes in channel width, bed elevations and thalweg position. This provides the basic data needed to quantify channel response to hydrologic and physical variables and the movement of streambed sediment.

Currently, 11 monumented cross sections are distributed along the mainstem and three tributaries of Mill Creek (Figure 1). Cross sections were monumented with 1.2 m lengths of 9.5 mm steel bar. Steel monuments were driven one meter into the ground and referenced to at least two other triangulation points. Triangulation was by tape and compass. Relative altitudes between end points were established by leveling (Nolan, 1979; Emmett, 1974). Cross sections were surveyed during the summer months from 1974-1985 with an automatic level and stadia rod. Cross section plots and calculations of scour and fill between the summers of 1980 and 1982 were accomplished with the assistance of the U.S. Forest Service Pacific Southwest Laboratory's computer facilities. Information and photographs on the condition of survey monuments, specific erosional or depositional features, bed forms, and bed material were obtained while surveying to assist in the interpretation of cross-sectional changes.

Figure 13 illustrates terms used in describing changes at the cross sections. The thalweg is the lowest point in the streambed in cross-sectional profile, and changes in thalweg elevation are denoted by ΔT. The streambed is the area that becomes completely inundated by winter flows. Net streambed area change (ΔA_s) is the net difference between scour and fill in the streambed.

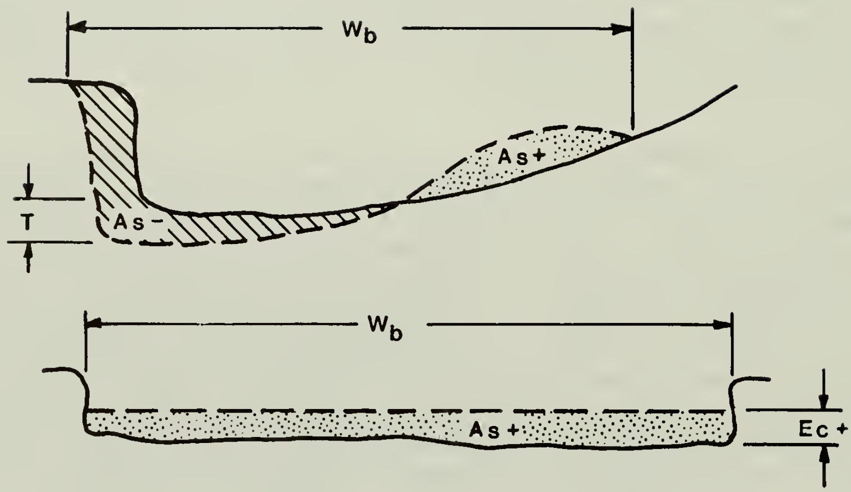
Stream banks in Mill Creek consist of either alluvium from floodplain deposits that rise 2 to 3 meters above the streambed or the base of hillslopes adjacent to the streambed. A bankfull width (W_b) was defined as the width of the channel inundated by bankfull flow (recurrence interval = 1.5 years). Criteria for defining this include vegetation breaks, highwater marks, breaks-in-slope and floodplain surfaces.

Another characteristic used to described variation at a cross section is change in the mean streambed elevation, E_c. To compare the relative importance of changes at cross sections of different widths, a normalized value was derived by dividing net change in streambed area (ΔA_s) by bankfull width, W_b:

$$\Delta E_c = \Delta A_s / W_b$$

B. Results

Figure 1 shows the location of cross sections in the Mill Creek watershed and Figure 6 shows the channel gradient at the cross sections.



———	Land surface at time of initial survey.
— — —	Land surface at time of resurvey.
W_b	Bankfull width
T	Change in altitude of thalweg associated with scour (−), or fill (+).
	Change in area associated with changing streambed altitude. As+ indicates aggradation. As− indicates scour. Net change in streambed area (ΔAs) = (As+) + (As−).
Ec	Elevation change in mean channel depth (net streambed change ÷ bankfull width). Ec+ indicates aggradation. Ec− indicates scour.

Figure 13. Terms and symbols used in cross-section analysis.

With only eleven cross sections monitoring channel changes in a 99 km^2 basin, it is difficult to place much confidence in interpreting cross-sectional changes as indicative of watershed trends as a whole; however, some important generalizations can be made.

Tables 12 and 13 summarize the results of cross section surveys for the years of data available. Cross sections with the highest magnitude of change were Cross Sections 1, 10, and 11. Five of the sections showed net scour and five net fill. Frequently the change in channel bed elevation was ±0.15 m/yr. This is a typical amount of scour and fill in a small gravel bed stream on the north coast (Madej, 1984) and is similar to that found in the upper reach of Redwood Creek (A=175 km^2).

An analysis of net changes in cross-sectional area (Table 13) shows that eight of the eleven cross sections scoured. The highest magnitude of scour occurred in lower Mill Creek at Cross Sections 10 and 11. Cross Sections 2, 3, and 6 show the highest relative magnitude of change (highest value of E_c).

Tributaries are relatively more active than the lowermost reach of Mill Creek. Cross Sections 1, 4, and 5 are among the most actively changing areas (Figure 14). All these sections are located at points of abrupt changes in channel gradient (Figure 6). These areas are natural sites of deposition. Many indicators of channel aggradation suggest that sediment deposition has been severe in recent years (Figures 14 and 15), especially at Cross Section 1. Large gravel bars, a poorly defined channel, lack of good pool-riffle sequence, low summer flow that goes subsurface through the gravel deposits in several locations, and finer-sized bed material than more stable reaches of the creek support the idea of recent aggradation. Pre-1974 cross section data are not available, however, so quantification of channel changes resulting from major floods in 1955, 1964, and 1972 is not possible. Channel aggradation has occurred since 1930 at Cross Section 11. A comparison of old and recent photographs shows over a meter of channel fill here (Figure 16). Aggradation in the Smith River may affect bed elevations at the mouth of Mill Creek. The bed of the Smith River at the gaging station, 2.5 km upstream of Mill Creek, aggraded 2 m as a result of the 1964 flood, and had not fully recovered as of 1980 (Lisle, 1981). Figure 17 shows the confluence of Mill Creek and the Smith River in the 1930's and in 1986.

A comparison of ΔE_c with ΔT shows how a channel changes through time. If net ΔT is greater than net ΔE_c, it implies that the thalweg or low flow channel is incising or aggrading more rapidly than the cross section as a whole (Cross Sections 1, 7, 8, 10, and 11). In contrast, if net ΔE_c is greater than net ΔT, channel change is accommodated by the entire cross section more than by adjustment of the low flow channel (Cross Sections 2, 3, 4, 5, 6, and 9). Most tributary cross sections fall in the latter category.

The total highest magnitude of change (scour and fill) for all cross sections occurred in 1974-75 (the year with highest peak discharges),

Table 12: Changes in Thalweg Elevation (m) at Mill Creek Cross Sections, 1974-1985

Cross Section	1974-75	1975-78	1979-80	1980-82	1982-83	1983-84	1984-85	Net change in thalweg
1	0.03	-.85	.52	-.30	.40	-	0	-.20
2	-.40	.40	-.15	.06	-.09	0	0	-.18
3	.06	.34	-.09	-.18	0	.09	0	.22
4	.27	-.18	.21	-.15	.18	-.15	0	.18
5	-	.03	.09	-.09	.21	-.12	0	.12
6	-.18	.27	.12	-.12	-.21	.12	0	0
7	.03	.12	-.06	.15	0	-	0	.24
8	0	.03	0	0	.21	0	-.09	-.27
9	.06	-.09	0	0	-.09	-.15	.12	-.15
10	.52	0	-.15	.37	.70	-.61	-.31	.52
11	-.76	0	.09	.12	0	.64	-.69	-.60

Table 13: Changes in Cross-Sectional Area (m^2) at Mill Creek Cross Sections, 1974-85

Cross Section	1974-75	1975-78	1979-80	1980-82	1982-83	1983-84	1984-85	Net change in Area	Net ΔE_c
1	-0.58	-3.55	1.38	-1.99	2.02	-	-	-2.72	-.14
2	-1.04	-7.51	1.65	- .46	-.90	1.28	-.66	-7.64	-.33
3	3.44	5.76	-.064	.76	.06	.70	.84	10.92	.66
4	3.10	-1.77	-	.56	.79	-.23	.86	3.31	.19
5	-	4.72	-.02	-1.55	1.20	-.14	-.22	3.99	.13
6	-1.15	.15	2.03	-2.41	-4.72	.25	-.62	-6.47	-.27
7	.80	-1.30	.09	.19	-.79	-	-.39	-1.40	-.06
8	.26	- .74	-.74	.98	-1.45	.14	.13	-1.42	-.07
9	.65	- .63	-.41	-.04	-6.45	1.19	.23	-5.46	-.17
10	4.78	-1.64	1.87	-7.97	11.32	-7.06	-4.27	-2.97	-.11
11	-5.17	4.05	0.41	- .83	.24	1.78	-1.66	-1.18	-.05

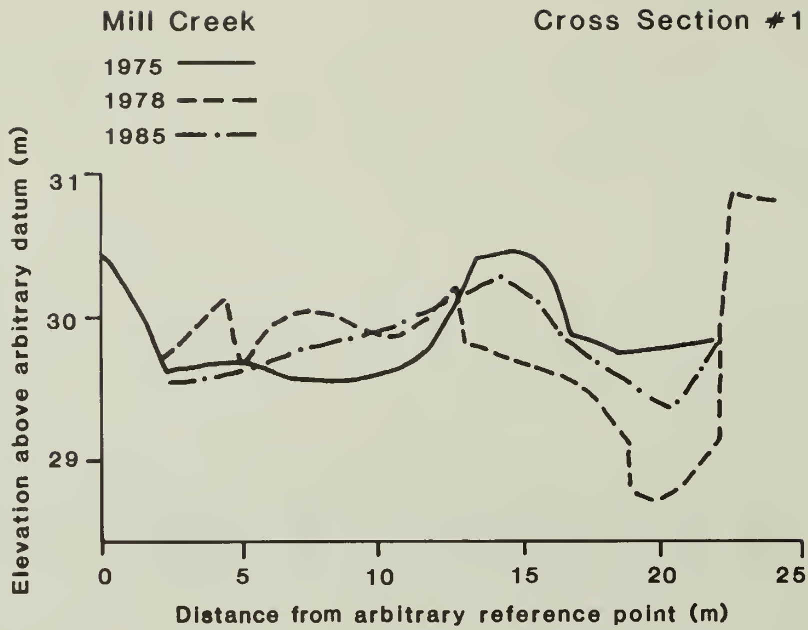


Figure 14. Plot of cross section surveys taken in 1975, 1978 and 1985 at Mill Creek Cross Section 1.

Figure 15. 1985 photograph of Mill Creek channel at Cross Section 1 looking upstream. Note large bars and cut logs.

Figure 16A. Photograph of Mill Creek taken in the early 1930's. Note large boulder with attached plaque exposed in channel.

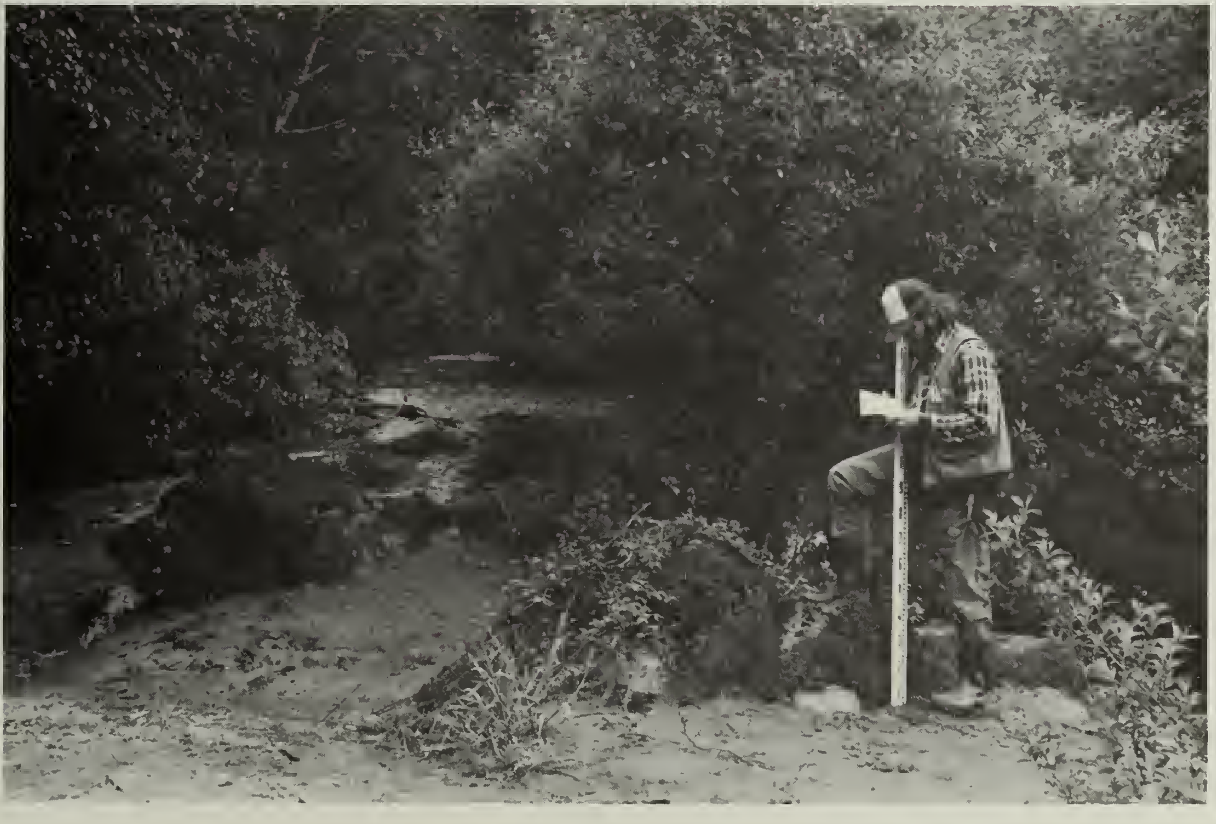


Figure 16B. Photograph of same area in 1986. Note boulder is buried, and base of survey rod is adjacent to the top of the plaque.

and subsequently in 1975-78. The lowest magnitude of change occurred in 1984-85 and in 1983-84.

In contrast to Redwood Creek, the low flow channel of Mill Creek remains in a relatively stable position from year to year. High alluvial terraces (2 to 6 m) in the upper reaches and even higher terraces (5 to 8 m) in the lower reach help confine the channel to its present location. Several cross sections show a high flow channel on low terraces at the base of the hillslopes. The response of these terraces and adjustments of the high flow channels during large floods is as yet unknown because an extreme flood (>100 yrs.) has not occurred during the period of available data.

Bank erosion is common, but not particularly severe, along the upper reaches of Mill Creek where banks consist of alluvium (Figure 18). Downstream, bedrock outcrops are more common along stream banks, and consequently bank erosion occurs less frequently. In steep tributaries (not monitored by cross sections), however, bank erosion was noted on aerial photographs.

In summary, the cross section record over the last 11 years shows general scour of the Mill Creek channel. The magnitude of change has decreased in recent years. Evidence exists of past channel aggradation; however, sedimentation is not a threat to the old growth redwood trees in the lower reach.

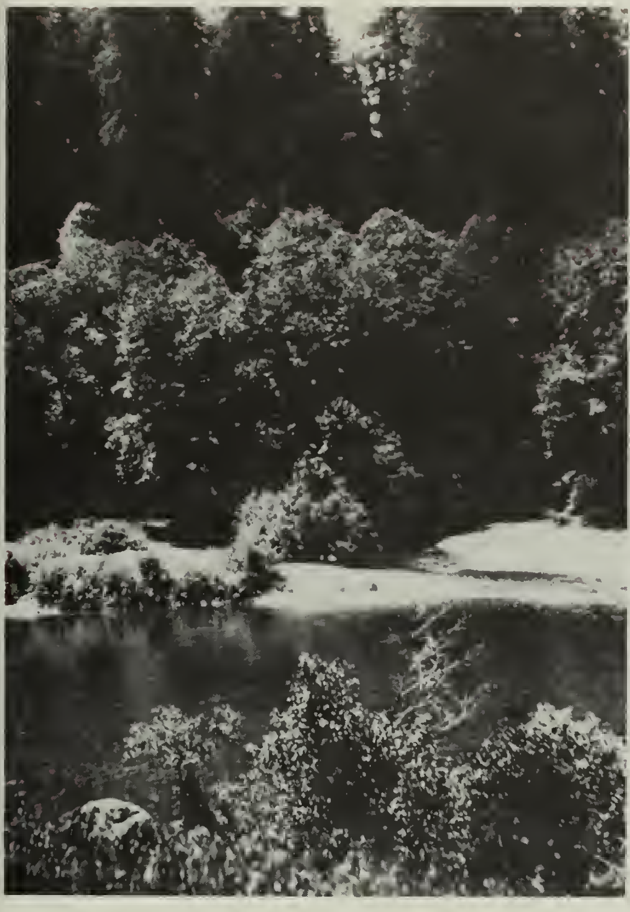


Figure 17A (left). Confluence of Mill Creek and the Smith River in the 1930's.

Figure 17B (right). Same location in 1986. Note that the mouth of Mill Creek is now a straight rather than a curved channel, and that the gravel bar on the Smith River is higher and unvegetated in 1986. Recent aggradation on the Smith River is documented at a gaging station 2.5 km upstream from this location.

Figure 18. Bank erosion along Mill Creek. Exposed roots indicate minimum amount of erosion.

VI. HYDROLOGY

The USGS monitored the streamflow and sediment discharge of Mill Creek from 1974 to 1981. The gaging station was located approximately 1 km downstream of the East Fork and West Branch confluence and monitored an area of 74.1 km^2 (Figure 1). Water discharge was measured continuously; suspended sediment and bedload were measured periodically. Surface water quality data were taken from 8 sites (Iwatsubo and Washabaush, 1982). The periods of record for surface water quality and a statistical summary of the data are listed in Iwatsubo and Washabaush (1982, Table 5 and Supplemental Data A).

A. Streamflow Characteristics

Dominant runoff characteristics of the Mill Creek basin are similar to those of other North Coast basins: a large but highly variable annual amount of runoff, a pronounced seasonal concentration of runoff and a high runoff-precipitation ratio. Rainfall is also seasonally distributed. The seasonal pattern of mean monthly runoff closely follows the seasonal pattern of mean monthly precipitation (Figure 19). Annual runoff varies from 15-99" (40-250 cm) (Table 14) and mean annual runoff is 70.82" (180 cm). Mean annual precipitation (Winston and Goodridge, 1980) is 102" (266 cm). Thus, there is a 30% loss between precipitation and runoff, a value typical for North Coast rivers.

Mill Creek closely mimics the runoff pattern of the Smith River (Table 15), although the Smith River has a higher runoff per unit area than Mill Creek. The correlation between the two stations is excellent ($r^2 = 0.988$). This suggests that Smith River runoff data can be used as a surrogate for Mill Creek now that the gaging station on Mill Creek is discontinued.

For Mill Creek, the lowest mean daily flow on record is 2.5 ft^3/s (0.021 m^3/s); the highest is 2980 ft^3/s (84.4 m^3/s). Mean annual discharge is 118 ft^3/s (3.34 m^3/s). The peak flood flow measured (4460 ft^3/s or 126 m^3/s) on March 18, 1975, was equivalent to other peaks on north coast rivers on a per unit area basis.

Water temperatures fluctuate seasonally, and vary with air temperature. Figure 20 shows maximum and minimum water and air temperatures on a monthly basis. Air temperature was measured at Crescent City, located on the coast. Mean summer air temperature for the Mill Creek basin is probably higher than that measured at Crescent City because temperatures increase inland with distance from the ocean.

B. Flood Frequency

The probability of a particular size flood occurring can be obtained from a flood frequency plot. Figure 21 is a log-Pearson Type III flood frequency plot for Mill Creek based on eight years of discharge measurements. In general a minimum of 10 years of record is necessary to formulate a precise flood frequency curve. Accordingly, the Mill

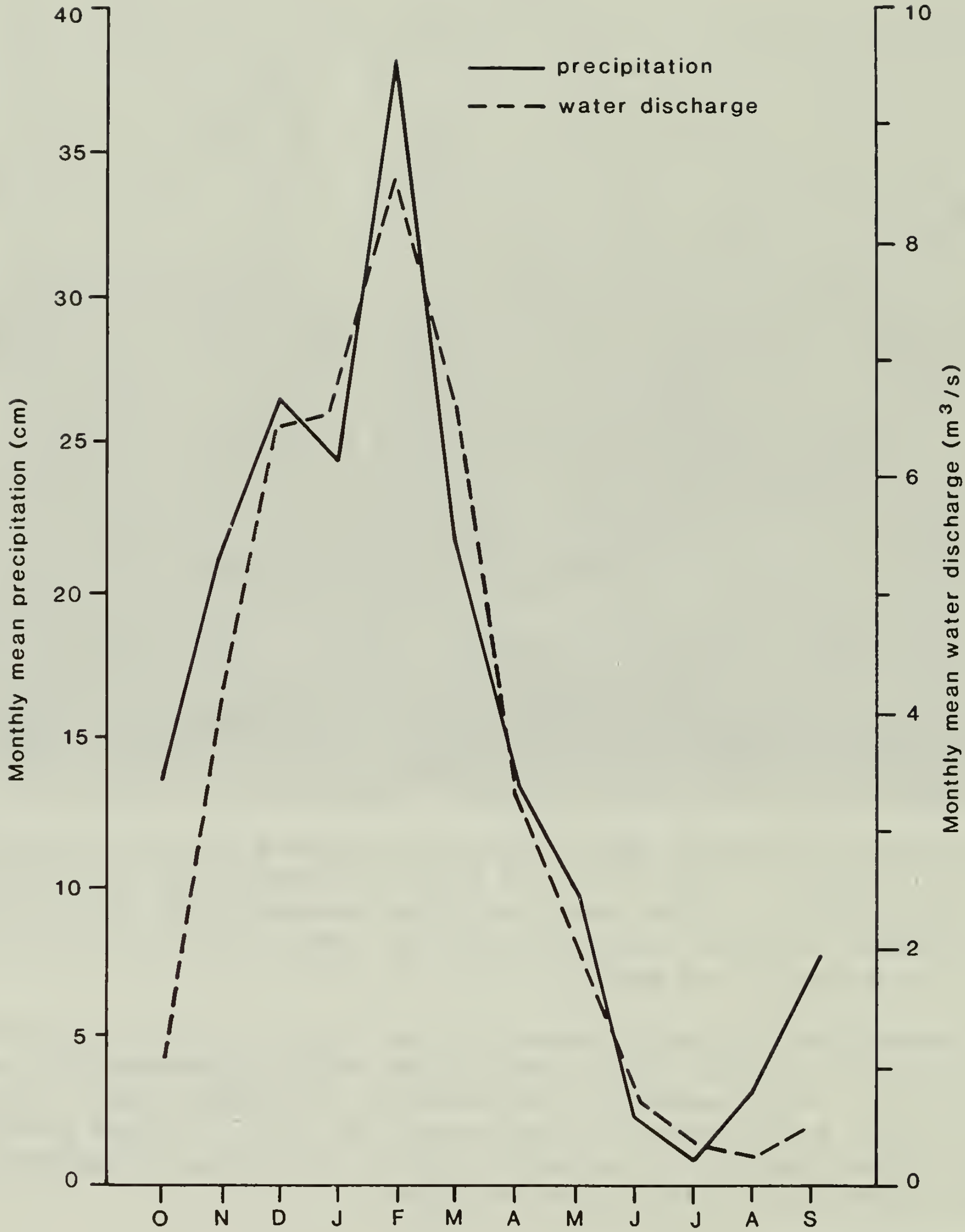


Figure 19. Plot of mean monthly precipitation against mean monthly water discharge based on data from 1974-1981. Both are strongly seasonally distributed. Runoff closely follows precipitation trends.

Table 14: Total Annual Discharge for Mill Creek
(Drainage Area = 74.1 km²)

Water Year	Annual Discharge (10^6 m^3)	Equivalent Runoff (cm)
1975	130.8	177
1976	96.3	123
1977	28.6	39
1978	186.2	251
1979	91.4	123
1980	120.8	163
1981	84.8	114

Table 15: Total Annual Discharge Per Unit Drainage Area
for North Coast Rivers
(10^6 m^3 of water/km^2 of drainage area, or m of runoff)

Water Year	Mill Creek	Smith River	Klamath River	Redwood Ck nr Blue Lake	Redwood Ck at Orick	Little Lost Man Creek
1974		3.98	0.60	2.09	2.14	---
1975	1.77	2.18	.54	1.74	1.62	1.34
1976	1.23	1.72	.34	0.95	1.05	0.91
1977	0.39	0.55	.12	0.23	0.24	0.24
1978	2.51	2.91	.62	1.33	1.45	1.36
1979	1.23	1.48	.31	0.71	0.78	0.73
1980	1.63	2.21	.60	1.38	1.37	1.15
1981	1.14	1.45	.31	0.71	0.80	0.86

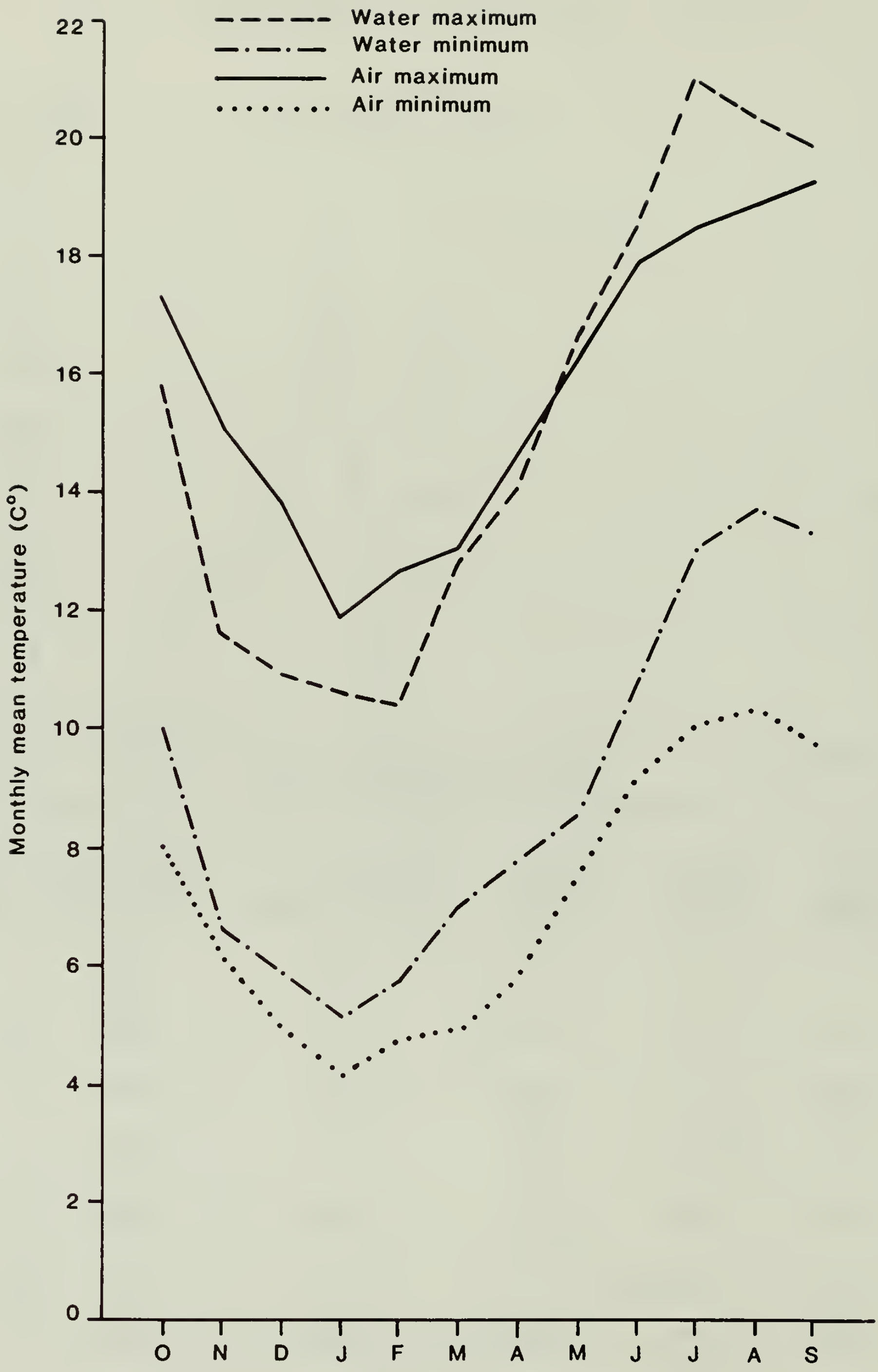


Figure 20. Plot of maximum and minimum air temperatures (measured at Crescent City) and water temperatures (measured at Mill Creek gaging station).

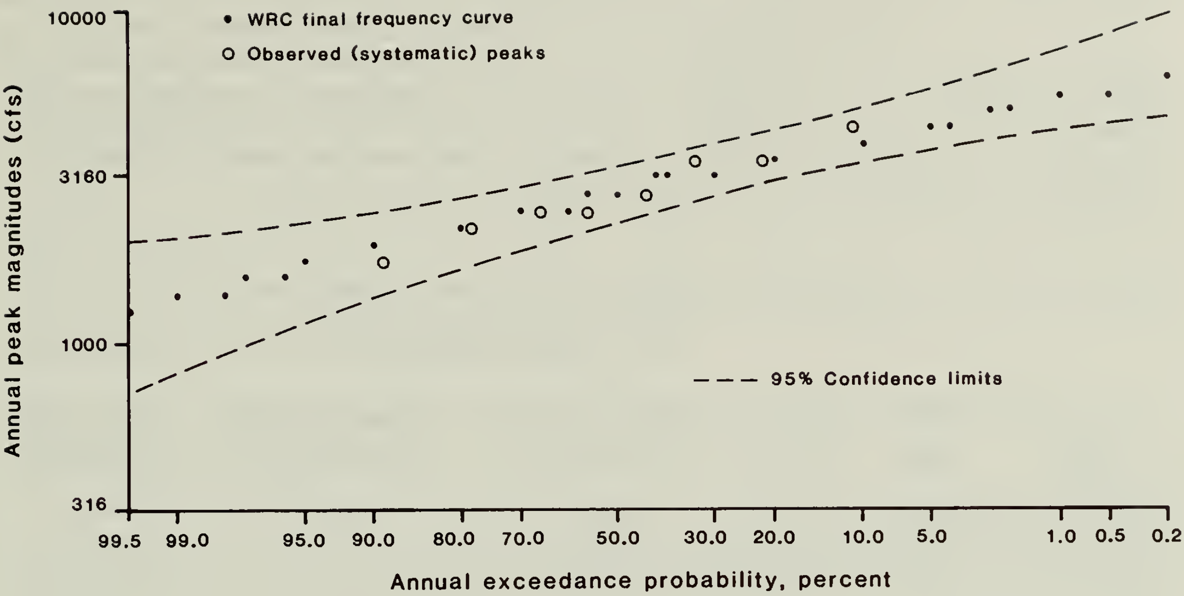


Figure 21. Log-Pearson Type III flood frequency plot for Mill Creek. Both observed peaks and peaks computed by the Water Resources Council's techniques are shown, as well as the 95% confidence limits for the data.

Creek flood record should be interpreted with caution. According to this plot the 10-, 50- and 100-year floods are 4060, 4960 and 5310 ft^3/s (115, 140, and 150 m^3/s) respectively. The 95% confidence limits are also shown. Bankfull flow has a 1.5 yr. recurrence interval, and for Mill Creek is about 2500 ft^3/s (70 m^3/s). The mean annual flood; that is, the mean of all annual maximum discharges, is considered to have a recurrence interval of 2.33 yrs (Dunne and Leopold, 1978). For Mill Creek this corresponds to a flow of 3000 ft^3/s (85 m^3/s).

These figures apply to Mill Creek at the gaging station, with a drainage area of 74.1 km^2. To estimate flood frequency at the mouth of Mill Creek (A=100 km^2) the approach described in "Magnitude and Frequency of Floods in California" (1977) was used. Values for the gaged station were extrapolated to the entire basin area. The 10-, 50- and 100-year floods at the mouth of Mill Creek calculated by this method are 5280, 6440 and 6880 ft^3/s (150, 182, 195 m^3/s) respectively.

Waananen and Crippen (1977) also list regression equations to calculate floods of different recurrence intervals for the north coast. The regressions are based on data from rivers from San Francisco to the Oregon border. These equations predict discharges almost twice that measured at the USGS gaging station. These equations should probably be adjusted for the high rainfall in the Mill Creek area, and must be used with caution, if at all, in this area.

A comparison of total annual discharge per unit area for Mill Creek and other north coast stations shows an interesting trend (Table 15). Discharge for Mill Creek is higher than all Redwood Creek stations for all years of record, and lower than the Smith River for the same time period. This is primarily due to rainfall differences among the watersheds. A similar comparison was made for peak discharges per unit area (Table 16). For storms which all watersheds experienced, Mill Creek usually showed higher values of discharge than Redwood Creek stations. Rainfall data for individual storms are not available, so more detailed analysis of these trends were not done.

Table 16: Comparison of Peak Discharges for North Coast Rivers (m^3/s per km^2)

Date of Flood	Mill Creek	Smith River	Redwood Creek nr Blue Lake	Redwood Creek at Orick	Little Lost Man Creek
01-16-74	1.09	1.58	0.57	.61	---
04-01-74	0.95	1.11	.92	.97	---
02-19-75	1.09	1.11	1.12	.78	68
03-18-75	1.71	2.32	1.97	1.97	2.56
03-25-75	1.06	1.16	0.94	.79	---
12-14-77	1.20	1.83	0.56	.83	1.24
01-11-79	0.95	1.44	.77	.56	.56
03-14-80	1.33	1.18	.69	.77	.72

C. Flow Duration

A flow duration curve is a cumulative frequency curve that shows the percentage of time during which daily discharges are equalled or exceeded during a given period (Searcy, 1959). The magnitude and variability of mean daily discharges of Mill Creek near Crescent City are shown by the flow duration curve based on streamflow records for the period 1975 to 1981 (Figure 22). The mean annual discharge (Q_{mean}) for the seven year gaging record was 118 ft^3/s (3.30 m^3/s), a flow equalled or exceeded 24 percent of the time (Figure 22). Mean annual discharge was also derived by a regression equation developed by Crippen (1970) for comparison:

$$Q_{mean} = (2.9 \times 10^3)\, A^{.98}\, P^{1.51}\, I^{.46}$$

A = drainage area = 28.6 mi^2
P = mean annual precipitation = 101.7 in
I = 2 year, 24 hour precipitation intensity = 6.5 in

This equation gives an annual mean discharge of 132 ft^3/s (3.70 m^3/s), with a standard error estimate of 20.3%. These two estimates of annual mean discharge show good agreement. The latter estimate is probably more realistic because the calculations based on the short gaging record included a severe drought year, thus lowering the mean.

Dimensionless flow duration curves are useful for showing discharge relationships between drainage basins (Emmett, 1974; Andre Lehre, personal communication, 1985) Dimensionless flow duration curves were plotted for several north coastal stream using discharge divided by annual mean discharge versus percent time flow was exceeded. They were then compared to the curve for Mill Creek (Figure 23). All basins are characterized by similar geology, vegetation cover, land use practices, and histories. Table 17 lists the period of record for each station, drainage area, and mean annual discharge.

Table 17: Characteristics of Stations Used in Dimensionless Flow Duration Curve

Basin	Period of Record	Drainage Area (km^2)	Q_{mean} (m^3/s)
Mill Creek near Crescent City	1975 - 1981	74	3.3
Little Lost Man Creek	1974-1982	9	0.4
Redwood Creek near Blue Lake	1953 - 1958 1973 - Present	174	7.5
Little River near Crannell[1]	1955 - Present	115	4.1
North Fork Mad River near Korbel[1]	1957 - 1964 1972 - 1982	105	4.0
Jacoby Creek near Freshwater[1]	1954 - 1964 1966 - 1972, 1974	15	0.4
Elk River near Falk[1]	1957 - 1967	114	2.3

[1]Lehre (Personal Communication, 1985)

The close fit of the Mill Creek curve in Figure 23 at high discharges suggests that the 7 year record is indicative of longer term tendencies, and that hydrologically, Mill Creek responds in a similar manner as

nearby rivers. Differences among the rivers become apparent at low flow, however. The amount of dry weather flow depends in part on the aquifer characteristics of the basin. Generally, rivers draining rock types with good aquifer characteristics have larger dry weather flows. In addition, changes in land use can alter flow duration characteristics. Channel aggradation and changes in the type and amount of vegetation can also affect flows. Channel aggradation causes some flow to go subsurface through gravel bars. The effects are most pronounced during low flow periods.

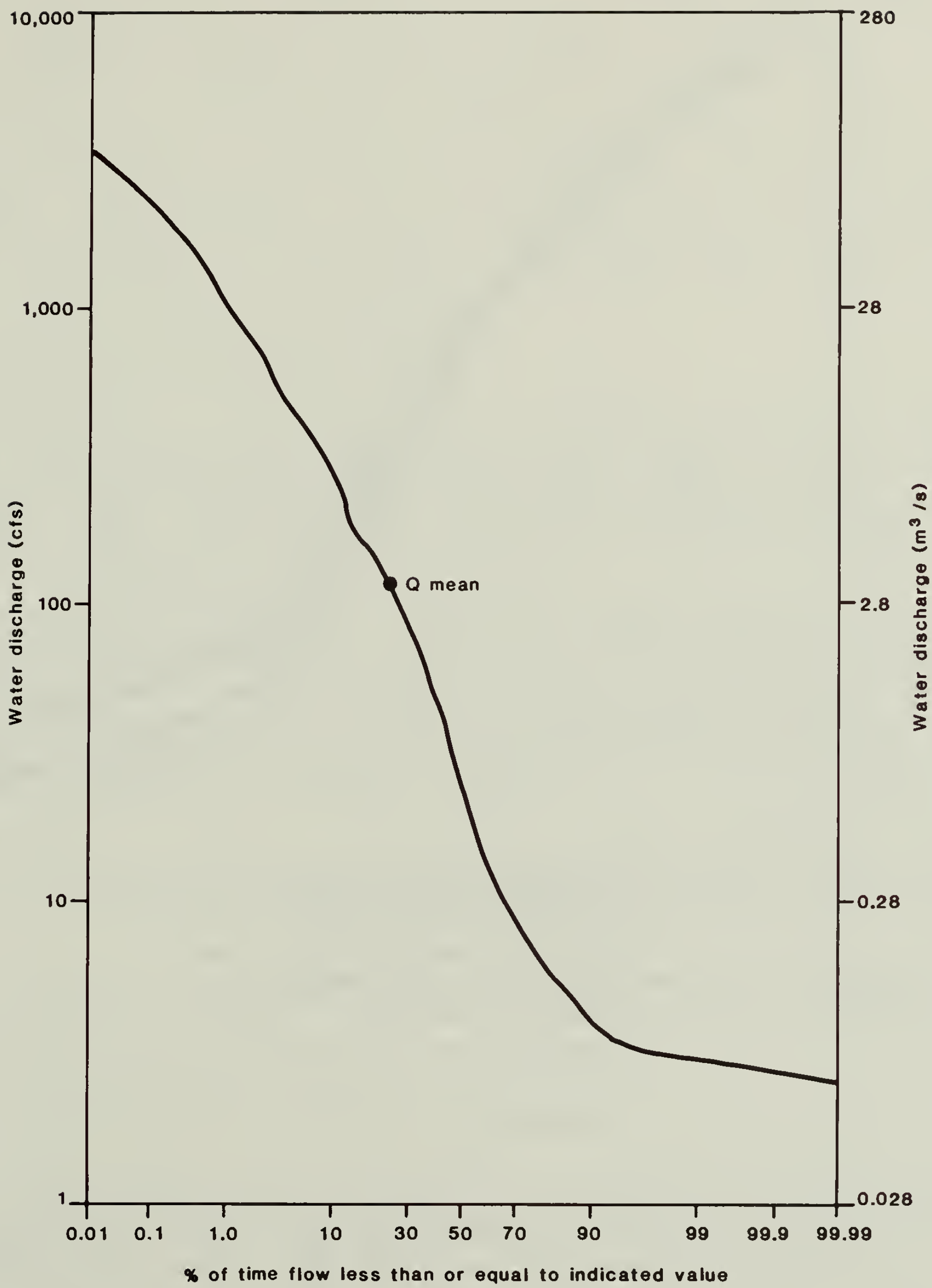
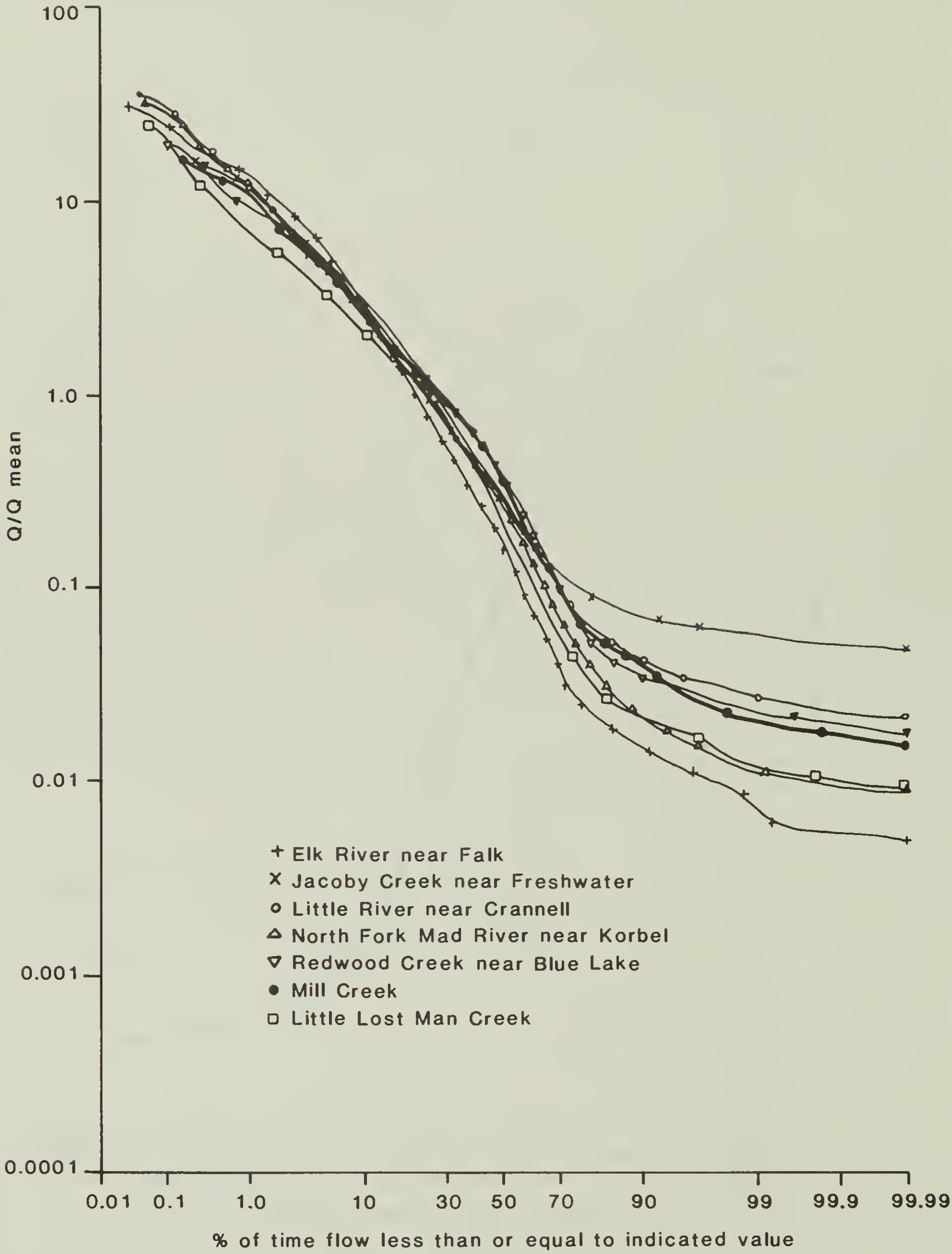


Figure 22. Flow-duration curve for Mill Creek at gaging station based on period of discharge record.



(after A. Lehre)

Figure 23. Regional dimensionless flow duration curves for seven north coast streams. All streams follow the same pattern at high discharge, but diverge at low flow.

VII. SEDIMENT YIELD

A. Sediment Characteristics

Sediment entering Mill Creek reflects the underlying geology and erosional processes of the basin. Banks are most often composed of terrace deposits, and bank erosion introduces this material into the active channel. The terrace deposits contain a large range of sizes, from fine sands to boulders. This range of particle size is also found in the channel bed. In addition to inputs from bank erosion along terraces, landslides and gullies contribute relatively competent sandstone to the channel. In Mill Creek sandstone is the predominant stream bed material. Attrition of bed material in Mill Creek is probably less than that estimated for Redwood Creek (Madej, 1984) because of differences in lithology.

1. Bed Material Size Distribution

Size distribution of bed material was sampled at each cross section location using the method outlined by Wolman (1954). Figure 24 shows changes in median size distribution (D_{50}) at the cross sections from 1983-1985. 'D_{50}' represents the size of bed material at which 50% of the material present is larger and 50% small.

Median bed material size (D_{50}) increased at Cross Section 1 in the West Branch of Mill Creek. An increase in the finer fraction was especially noticeable at Cross Section 2, where D_{10} rose from 2 mm to 22 mm. The highest increases occurred in areas of greatest scour. Cross Section 4 on Bummer Lake Creek also showed a small increase in size (D_{25} went from 2 to 8 mm), although D_{50} decreased slightly.

Cross sections on the East Fork of Mill Creek, in contrast, had a decrease in bed material size. For example, D_{50} fell from 73 mm to 36 mm at Cross Section 7, where aggradation occurred across the section.

At cross sections on the mainstem of Mill Creek, bed material size either stayed the same or decreased. These mainstem cross sections showed net scour from 1983-85.

2. Size Distribution of Sediment in Transport

Bed material is much coarser than bedload. D_{50} ranged in size from -4.5 to -6.5 ϕ (22 to 90 mm) for bed material, contrasted with -1 to -4.5 ϕ (2-22 mm) for bedload. Thus, when the streambed is mobilized the median size of material that is moving is smaller than the median size of the stationery bed. The size distribution of suspended sediment showed less variation than that of bedload. D_{50} of suspended load was most commonly 5.5 ϕ (0.022 mm). The West Branch and East Fork of Mill Creek showed more variation than the mainstem. D_{50} ranged from 2 to 6 ϕ (0.016 - 0.25 mm) for these tributaries. Figure 25 shows typical bedload and suspended sediment size distributions for Mill Creek.

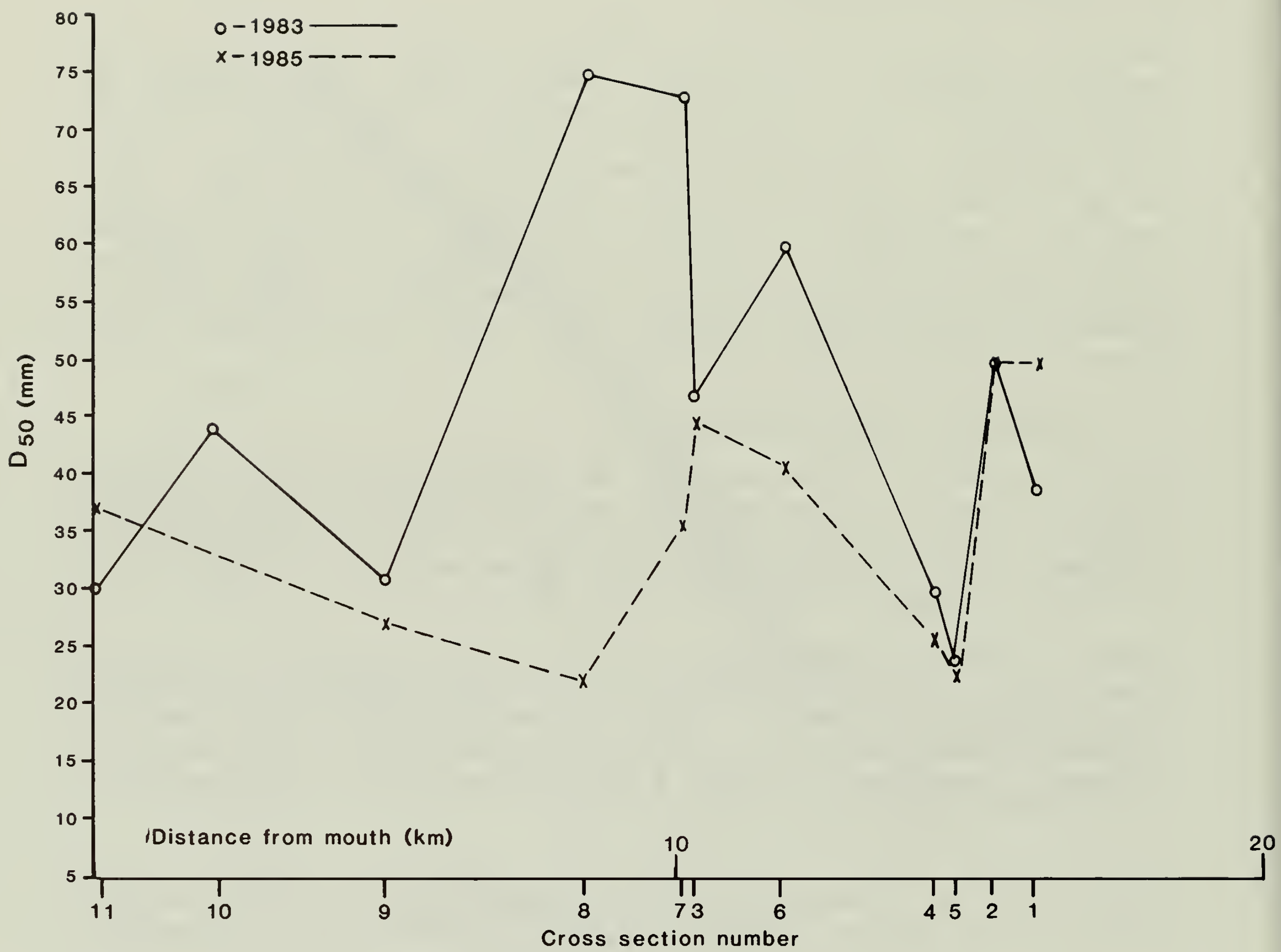


Figure 24. Plot of median bed material size (D_{50}) measured at cross sections in Mill Creek in 1983 and 1985. The lines connecting the points have no physical meaning, but are shown to help illustrate differences between 1983 and 1985 data.

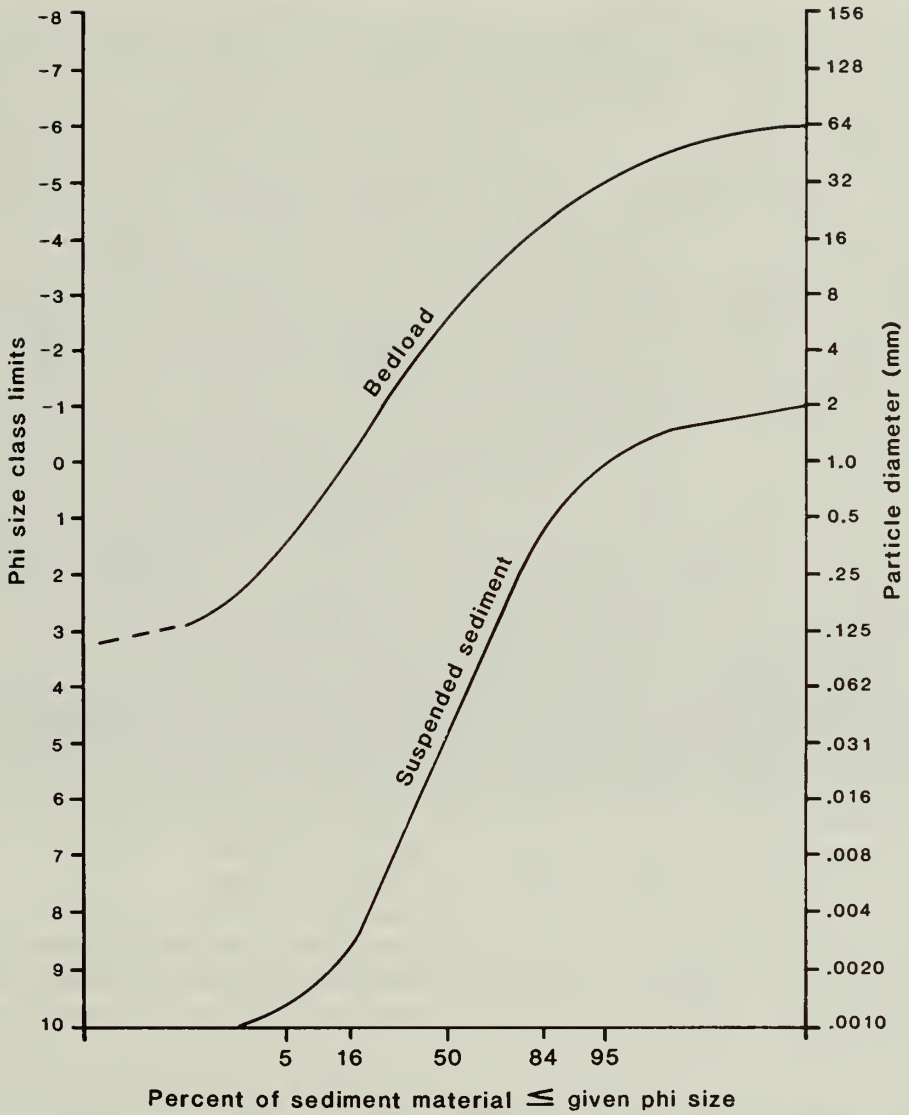


Figure 25. Average size distribution curves for bedload and suspended samples. Samples were collected at high flows from 1974-1980.

B. Sediment Storage

The temporary storage of sediment in stream channels and valley bottoms has been shown to be important in influencing the sediment yield of certain basins (Trimble, 1981; Madej, 1984). Sediment storage in Mill Creek was roughly calculated by mapping the area of gravel bars and terraces from aerial photographs. Heights of bars and terraces were measured by cross section surveys and by field checks in unsurveyed reaches. Volume was calculated as the product of bar/terrace height and area.

Sediment was divided into two categories: active channel and stable sediment (Figure 26). Active channel sediment is easily mobilized and is transported during moderately high flows (2-20 year recurrence intervals). In contrast, stable sediment lies high above the thalweg (2-8 m) and is only inundated or eroded during extreme high magnitude events. Alluvium stored in terraces that are high above the creek bed (>8 m) and are not directly contributing sediment to Mill Creek is not included in the storage estimate. Many terraces in Mill Creek are in this latter class.

Most active channel bars are too small to show at the map scales used in this report. However, larger floodplain deposits were mapped and are shown as alluvium in Figure 4. It is important to note that these are only rough estimates of stored sediment and field mapping is needed to refine these estimates.

In Mill Creek, active channel sediment (72,600 m^3) is one percent of the total stored sediment volume, V_s. On a per unit area basis, Mill Creek stores about 700 m^3/km^2 as active channel sediment. In contrast, Redwood Creek upstream of the USGS gaging station at Orick near its mouth stores almost 5000 m^3/km^2 of active sediment, with active channel sediment representing 13% of total V_s (Madej, 1984).

Total volumes of sediment (active channel plus stable sediment) on a per unit basis are 74,000 m^3/km^2 for Mill Creek and 22,000 m^3/km^2 for Redwood Creek. This is in sharp contrast to the figures for active channel sediment alone.

The spatial distribution of sediment is different in the two basins. In Redwood Creek 66% of all active channel sediment is in the downstream half of the river, as opposed to only 19% for Mill Creek. Stable sediment in Mill Creek is about equally distributed between the upstream and downstream halves of the basin. The same is true for Redwood Creek.

These differences in relative amounts and distribution of channel stored sediment may affect sediment yield rates in several ways. First, Redwood Creek has a much larger amount of stored sediment in its channel bed which is readily available for transport. The high rates of sediment transport in Redwood Creek are partly due to transport of channel bed material. Second, a relatively smaller amount of active channel sediment is stored in the lower half of Mill Creek than in the

Figure 26. Alluvial terrace along Mill Creek. Note coarse alluvium near base of terrace and finer material on top. Extensive redwood forests typically cover the surface of these terraces. Active channel sediment consists of channel bed material and the cobble bar in the foreground.

lower reach of Redwood Creek. Upper reaches that store a large portion of sediment tend to buffer the sediment yield measured downstream. Finally, Mill Creek stores much more stable sediment, on a per unit basis, than Redwood Creek. The wide valley bottoms not only provide a temporary storage site for sediment, but they also protect the base of hillslopes from erosion, thereby decreasing sediment input that would arise from slope instability problems. Extensive floodplains are located upstream of the USGS gaging station where the steep headwater tributaries suddenly flatten out. Sediment generated in the steep headwaters can be 'trapped' on these floodplains for long periods of time. Sediment yield measured at the gaging station downstream of the wide floodplain area may not be representative of the transport rates of streams entering this flat-lying area. Past aggradation of the channel bed in these floodplain areas is suggested by field evidence, as discussed above.

The tectonic history of the Mill Creek basin is not well known. Past episodic uplift of the basin may explain why low-lying floodplains exist in the upper basin and are absent in the downstream reaches.

C. Sediment Discharge

1. Suspended Sediment

Annual sediment discharge is an approximation of the yearly amount of sediment being transported past a certain point by the stream. Sediment discharge changes from year to year depending on sediment supply to the stream and on the magnitude and timing of streamflow. North coast rivers with daily records of suspended sediment discharge show that 90 percent of the annual sediment yield is typically tranported during high flows that occur less than 5 percent of the time (Janda and others, 1975). Large floods and land use have also been shown to severely affect sediment discharge relationships in many north coast streams (Hickey, 1969; Denton, 1974; Kelsey, 1977; Lisle, 1981).

Iwatsubo and Washabaush (1982) estimated long-term suspended sediment discharge for the Smith River and selected tributaries including Mill Creek. These estimates were based on a regression equation developed by Anderson (1979) using variables such as hydrology, geology, physiology and meteorology (Iwatsubo and Washabaush, 1982). The regression model was used to predict present sediment yields and sediment yields prior to road construction or logging. For the Mill Creek basin, present suspended sediment was estimated at 389 tonnes/km^2 (1114 tons/mi^2). Suspended sediment yield expected under natural conditions was estimated at 65 tonnes/km^2 (187 tons/mi^2). This represents a nearly 600 percent increase in the estimated long-term suspended sediment yield from natural to present conditions and was the highest percent increase for the 24 Smith River basin sites in the study.

Measured data at the Mill Creek near Crescent City gaging station (USGS, 1975 - 1981) indicate that suspended sediment discharge is much lower than that predicted by the above model. Thirty-two measurements of instantaneous peak discharge and instantaneous suspended sediment discharge (above 1.0 tonne/day) for the periods 1974-1977 and 1978-1981 were plotted on log-log axes (Figure 27). A regression equation was calculated to describe the best fit relationship between water and suspended sediment discharge. This equation was then used to predict sediment yields for given discharges, using measured flow duration values. Table 18 lists the annual sediment yields estimated by this method. The mean annual suspended sediment yield between 1975 and 1981 estimated by this method is 70 t/km^2, about one-thirteenth of the quantity estimated by Anderson's model used by Iwatsubo and Washabaugh (1982).

Hawkins (1982) shows that the slope of the line (n) in the relationship $Q_{ss} = kQ^n$ is 2.08 - 2.36 for other north coast streams. Mill Creek falls in this range (n = 2.28). This indicates that suspended sediment discharge increases with water discharge at a rate similar to that of

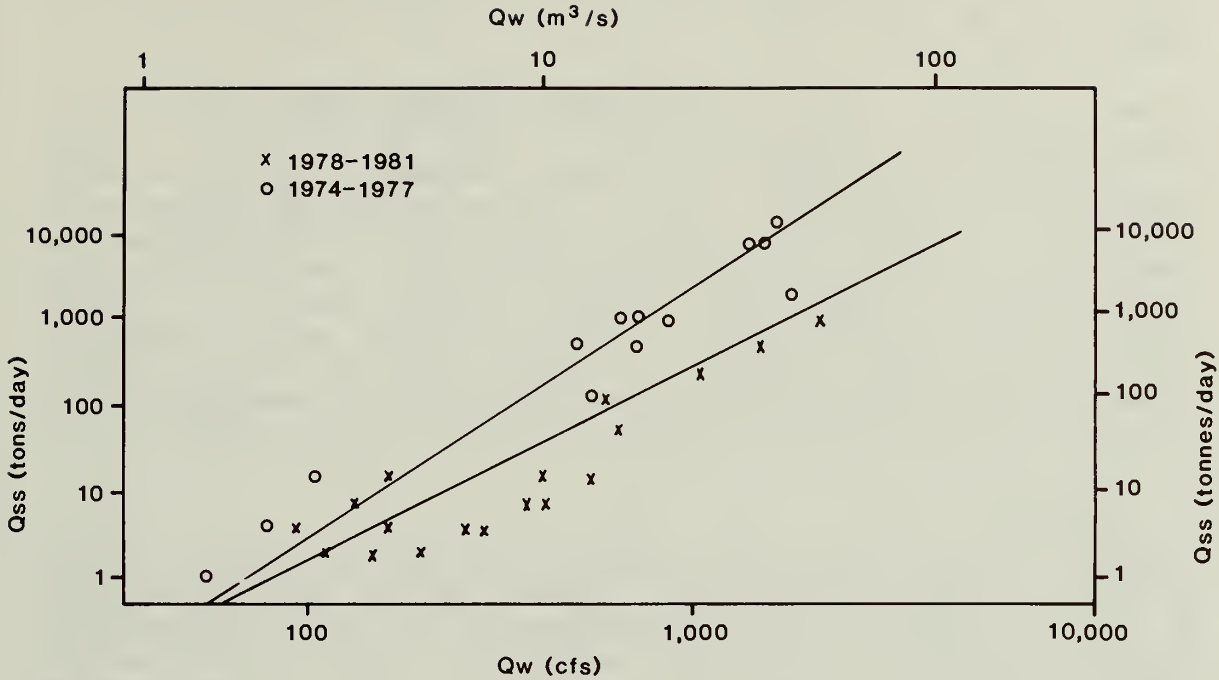


Figure 27. Sediment transport curves for Mill Creek for two time periods: 1974-1977 and 1978-1981.

Table 18: Annual Sediment Yields For Mill Creek, 1975 - 1981, based on sediment rating curve (USGS, Water Resource Data.)

	Suspended - Sediment Yield	
Year	tonnes/year	tonnes/km²
1975	8723	120
1976	2690	35
1977	311	4
1978	13639	185
1979	3365	45
1980	5583	75
1981	2980	40
Mean	6160	70

other north coast streams but that the total volume of sediment transported is less (i.e. 'k' is lower). Figure 28 shows a comparison of Mill Creek with Redwood Creek. For any given unit discharge, Mill Creek is transporting up to two orders of magnitudes less sediment than Redwood Creek.

Sediment transport curves for 1974 - 1977 (n=19) and 1978 - 1981 (n=13), show two distinct relationships: $Q_{ss} = 0.0001\ Q^{2.37}$ and $Q_{ss} = 0.0001\ Q^{2.12}$. This indicates that the rate of sediment transport increased more rapidly with discharge early in the record and has decreased in recent years. Interestingly, Redwood Creek sediment records show the same trend. Knott (1971) demonstrated that the 1964 flood in this region caused a steepening in sediment transport curves for several years. Perhaps the 1975 flood had a similar effect on Mill Creek, and subsequent data are showing a recovery from the flood effects. Alternatively, 1978-81, being a drier period than is average for this region, may have provided less sediment available for transport.

2. Bedload

A bedload rating curve was not constructed because an inadequate amount of bedload samples was collected. However, bedload constitutes 10-30% of the total sediment load in nearby streams and it is reasonable to expect Mill Creek to be in this same range. Median size of bedload material sampled (D_{50}) ranged from -1 to -4.5 ϕ (2-22 mm) and averaged 3.5 ϕ (11 mm). These values are similar to those measured in Redwood Creek.

3. Dissolved Load

Several types of water quality measurements have been made on Mill Creek and are summarized by Bradford and Iwatsubo (1978) and Iwatsubo and Washabaugh (1982). In addition to suspended sediment and bedload transport, streams remove material from a watershed through dissolution. Total dissolved solids measured in water samples are an indication of the amount of dissolved load in a stream.

In 1974-75 water samples were collected over a full range of flows; 46 samples were collected and analyzed. Mean concentration of dissolved solids was 33 mg/L (standard deviation of 7.2 mg/L). Values at high flows were below the mean (21 mg/L was the lowest observed value) and those at low flows were above the mean (49 mg/L was the highest observed value). A lower concentration during peak flows is not uncommon, and is related to dominant runoff processes.

In summer, baseflow is the main contributor to water discharge. This water is in contact with soil and rock for a relatively long period of time and therefore tends to be higher in dissolved solids. Soil water temperature is probably higher in summer, further increasing the amount of minerals dissolved in the water. In contrast, stormflow (produced by saturation overland flow, Horton overland flow and subsurface stormflow) provides little time for water/soil contact and low concentrations of dissolved loads result. If rainfall intensity exceeds soil infiltration

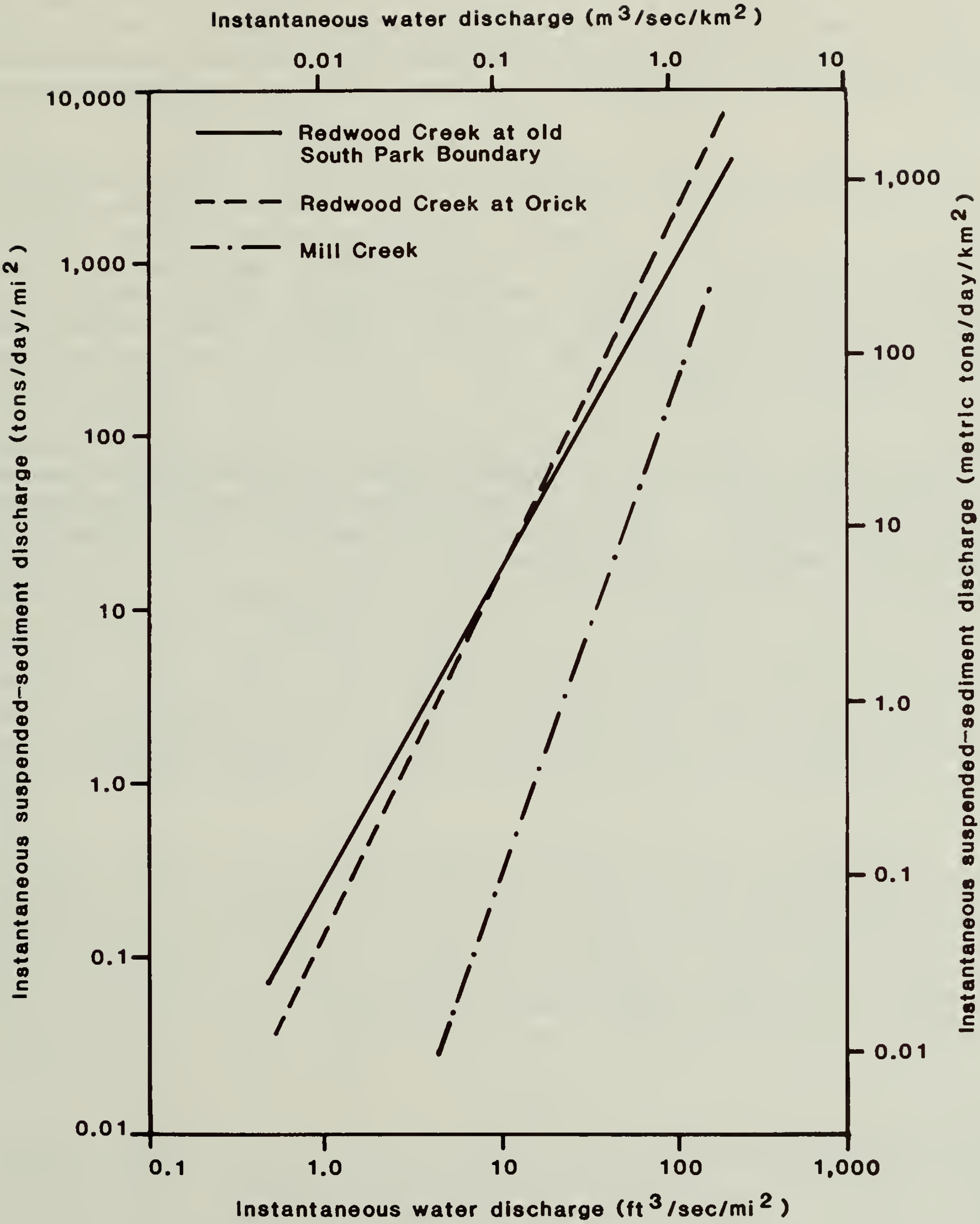


Figure 28. Normalized sediment transport curves for Mill Creek and two Redwood Creek stations. Although sediment discharge increases at a faster rate in Mill Creek than in Redwood Creek, the magnitude of sediment discharge at all discharges on record is much less in Mill Creek.

rates Horton overland occurs. Under pristine forested conditions in Mill Creek this type of overland flow is not seen, but it can occur on paved and main haul roads and compacted areas. Bradford and Iwatsubo (1978) suggest that dilution of dissolved solids is more pronounced and occurs more often in logged watersheds due to changes in runoff processes.

Dissolved solids concentrations are combined with flow duration data to provide an estimate of total dissolved load. For Mill Creek this is 3450 tonnes/yr. (47 t/km^2). With an annual suspended sediment discharge of 6160 tonnes/yr, this value is somewhat higher than normal. Although dissolved solid concentrations are not high in Mill Creek, a large amount of total runoff results in a total dissolved load per unit area that is high in comparison with more arid regions of the United States (Dunne and Leopold, 1978).

Total load past the Mill Creek gaging station is about 10,500 tonnes/yr and includes 6160 tonnes/yr of suspended load, 925 tonnes/yr of bedload, and 3450 tonnes/yr of dissolved solids. Dissolved load constitutes one third of the total load, which is somewhat high, although not exceptionally high for U.S. streams.

VIII. DISCUSSION

A comparison of Mill Creek with other north coast streams shows many similarities and some striking differences. The Mill Creek basin receives more annual rainfall than many other basins on the north coast and as a result produces more runoff, on a per unit area basis, than other north coast rivers, except for the Smith River. In both watersheds annual runoff as a percentage of total precipitation is similar, and the vegetation and land use histories are also similar.

An obvious question arises: Why are sediment yields so much lower in Mill Creek than in other north coast rivers such as Redwood Creek, the Eel River, and the Mad River (Table 19)? The physiographic characteristics of the basin (Table 5) give little indication that sediment yields should be lower. The relief ratios show that Mill Creek has relatively more relief than most of Redwood Creek. Average hillslope gradients are also higher in Mill Creek. The hypsometric values indicate that hillslopes steepen near channels more so in Mill Creek than in Redwood Creek (although terraces directly adjacent to the creek buffer the effects of steep slopes). Drainage densities in Redwood and Mill Creek watersheds are similar. Stream gradients are more gentle in lower Redwood Creek where drainage area is much greater than Mill Creek. Redwood Creek follows the trace of the Grogan Fault for much of its length causing the basin to be much more elongated than the Mill Creek basin. As a consequence, Redwood Creek has many more small tributaries and, only Prairie Creek contributes more than 6% of the total drainage area. In contrast, the two major tributaries in Mill Creek are about equal in size and contribute 75% of the total drainage area.

A major reason for lower sediment yields in Mill Creek lies in the geology of the region. The rocks underlying the Mill Creek basin are not as highly sheared and fractured as those in the Redwood Creek basin. Attrition of bed material to suspended sediment is probably less in Mill Creek as compared to Redwood Creek. Uplift rates may be different from areas farther south, although detailed studies similar to the terrace investigations around Humboldt Bay and Trinidad (Stephens, 1982) have not been done in this area.

The types of soils and their distribution in the basin also affects sediment yields. The Mill Creek basin has more Melbourne and Josephine soils than the Redwood Creek basin. The higher clay and iron contents of these soils promote aggregate stability and result in lower sediment yields, even when the soils are disturbed by timber harvest activities. Fewer areas of Atwell soils lead to fewer landslides and earthflows in Mill Creek. Melbourne and Josephine soils are more developed pedogenically than the Hugo soil in Redwood Creek.

A high percentage of relatively competent sandstone underlying the Mill Creek basin contributes significantly to lower fluvial erosion rates. Weaver and others (in press) have shown that in areas of the Redwood Creek basin underlain by coherent sandstone bedrock, fluvial

Table 19: Measured and Estimated Suspended Sediment Yields at North Coast Gaging Stations

Station	Drainage Area (km^2)	Period of Record Water Years	Suspended Sediment Yield ($tons/km^2$)
Eel River at Fort Seward	5457	1958-1968 1966-1976	2400[a] 1600[b]
Middle Fork Eel River near Dos Rios	3844	1958-1968	1995[a] 930[c]
Mad River near Arcata	1256	1958-1974	2000[b]
Redwood Creek at Orick	720	1954-1980	1850[d]
Redwood Creek at old South Park Boundary	474	1954-1980	2100[d]
Redwood Creek near Blue Lake	175	1954-1980	2100[d]
Panther Creek (Redwood Creek tributary)	15.7	1980-1984	250
Coyote Creek (Redwood Creek tributary)	20.2	1980-82, 1984	1900
Lacks Creek near Orick	43.8	1981-1984	700
Mill Creek near Crescent City	76.8	1975-1981	70
Smith River near Crescent City	1577	1978-79, 1981	170

[a]Brown and Ritter (1971)
[b]Janda (1979)
[c]Weighted long-term estimate (Knott, 1971)
[d]Crippen, unpublished data

erosion rates due to gullying are four times less than from areas on more incompetent sandstone.

Because the bedrock underlying the two basins is the same age, long-term landscape evolution of Mill Creek may have produced a better weathering environment for soil development. Lower uplift rates, less shearing, better drainage and more easily weathered bedrock are variables that

might contribute to the degree to which soils develop over time (Popenoe, personal communication). Thus geology, soils, and sediment yield are intricately related.

Another factor that may influence sediment yields in Mill Creek is sediment storage in the stream channels. Abundant terraces store vasts amounts of sediment upstream of the gaging station. Much sediment is stored in the upstream floodplain where the steep headwater channels abruptly flatten (Figure 6). If these areas are efficient sediment traps, sediment may be deposited and stored there over time, resulting in a low sediment yield downstream.

In Redwood Creek most major landslides occur on steep, streamside hillslopes in the inner gorge (Kelsey and others, in press). Landslides contribute a third to a half of the sediment load in Redwood Creek (Kelsey and others, 1981). In contrast, though the hillslopes of Mill Creek are steep, a well developed inner gorge is not present in the upstream reaches where timber harvest has occurred. The downstream-most reach of Mill Creek is incised deeply into strath terraces. Here, however, the bedrock is competent, no timber harvest or major road construction has occurred, and debris slides are rare. Therefore, streamside landslides are relatively rare and their associated sediment inputs are minimal in Mill Creek.

IX. CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

1. Timber harvest of old-growth forests and younger stands will continue in the upstream half of the Mill Creek basin. Aerial photographic coverage of the basin should be obtained regularly (every few years) to document any changes in erosional features, channel pattern, road construction and timber harvest activity.

2. The magnificent old growth redwood groves near the mouth of Mill Creek are not seriously threatened at the present time, although over a meter of streambed aggradation since 1930 is well-documented in this area. The trees are located on high terraces that are still unaffected by channel changes. Most of these trees would be safe even if additional aggradation occurs. Nevertheless, cross section surveys should be expanded and continued throughout the watershed to monitor channel changes.

3. There is no immediate need to reinstitute the gaging station on Mill Creek. Sediment yields measured at this station in the past were much lower than for stations on Redwood Creek. Water discharge data from the gaging station on the Smith River near Crescent City can be used to reconstruct probable runoff trends in Mill Creek. The Smith River station should not be used as a surrogate for sediment trends, however, because the geology is different from Mill Creek.

4. Precipitation measuring devices should be installed on park lands, and additional data should be obtained from the U.S. Forest Service on a regular basis to document rainfall patterns in this watershed.

5. A more detailed map of Mill Creek within park boundaries should be constructed to document specific areas of bank erosion and sediment storage. The map would be useful in determining the relationship of the redwood trees growing on the terraces to recent channel changes.

6. Trends in the Smith River (water and sediment discharge, changes in channel pattern) should also be carefully monitored because downstream reaches of Mill Creek will be affected by changes in the Smith River.

7. This report should be updated in five years, or sooner if a major flood should occur in Mill Creek.

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